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(12) **United States Patent**
Fanton et al.

(10) **Patent No.: US 12,013,010 B2**
(45) **Date of Patent: Jun. 18, 2024**

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(54) **DEVICES, SYSTEMS AND METHODS FOR SHOCK ABSORPTION**

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(72) Inventors: **Michael G. Fanton**, Los Altos, CA (US); **August G. Domel**, Palo Alto, CA (US); **Hossein Vahid Alizadeh**, Mountain View, CA (US); **David B. Camarillo**, Stanford, CA (US)

(73) Assignee: **The Board of Trustees of the Leland Stanford Junior University**, Stanford, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 174 days.

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§ 371 (c)(1),
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PCT Pub. Date: **Apr. 1, 2021**

(65) **Prior Publication Data**

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(51) **Int. Cl.**

F16F 9/10	(2006.01)
A42B 3/12	(2006.01)
F16F 9/08	(2006.01)

(52) **U.S. Cl.**
CPC ***F16F 9/106*** (2013.01); ***A42B 3/121*** (2013.01); *F16F 9/08* (2013.01); *F16F 2222/12* (2013.01); *F16F 2228/001* (2013.01); *F16F 2230/36* (2013.01); *F16F 2236/04* (2013.01)

(58) **Field of Classification Search**
CPC .. F16F 9/106; F16F 2222/12; F16F 2228/001; F16F 2230/36; F16F 2236/04; F16F 9/08; F16F 9/062; A42B 3/121
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,579,186 A	*	12/1951	Haboush	A61B 17/1721 378/162
3,994,022 A	*	11/1976	Villari	A42B 3/121 2/909
7,774,866 B2		8/2010	Ferrara	

(Continued)

FOREIGN PATENT DOCUMENTS

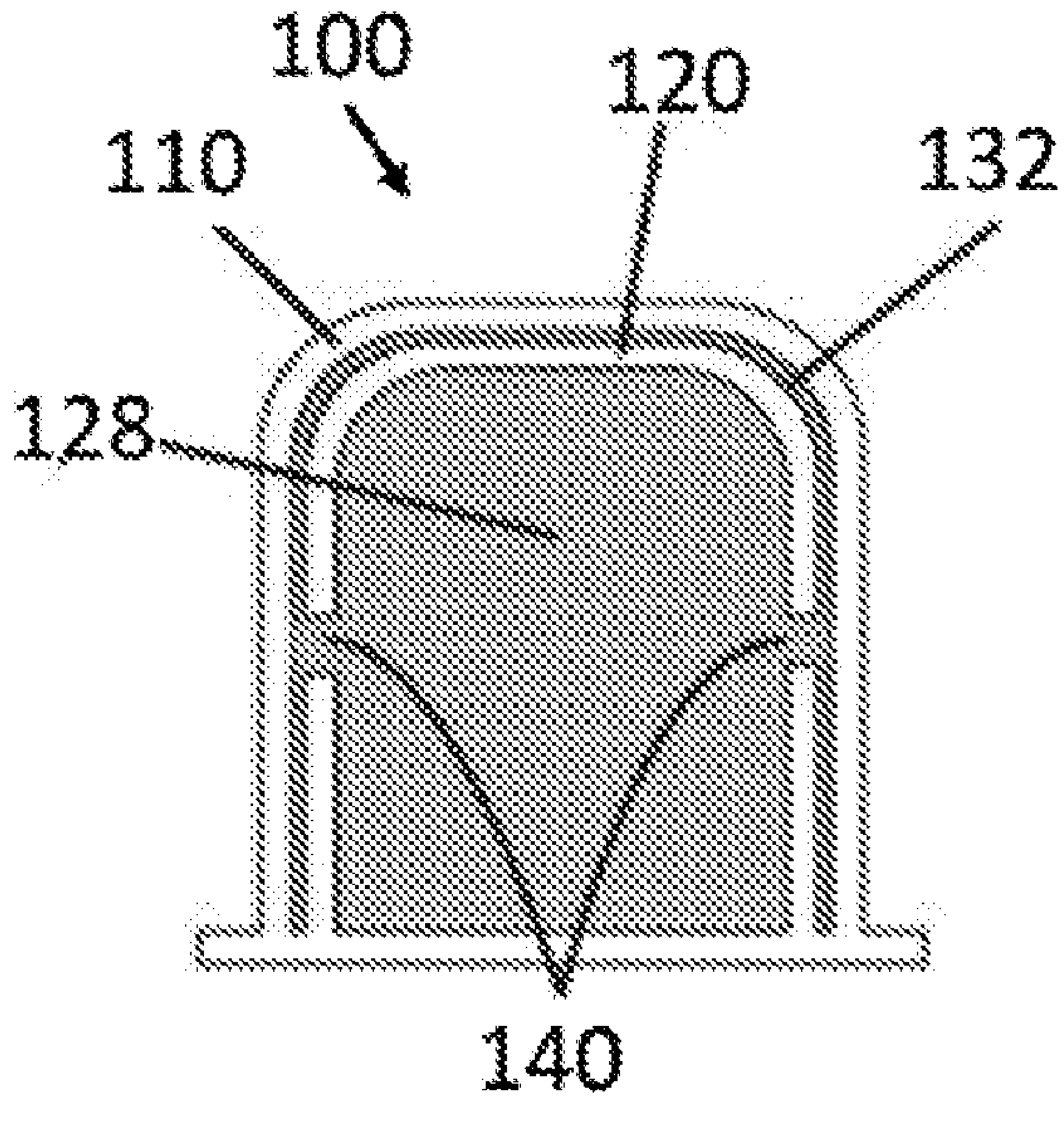
CN	104514837 A	*	4/2015	.... A42B 3/121
WO	WO-2006089235 A1	*	8/2006	.... A41D 13/0155
WO	WO-2018148753 A1	*	8/2018	.... A42B 3/064

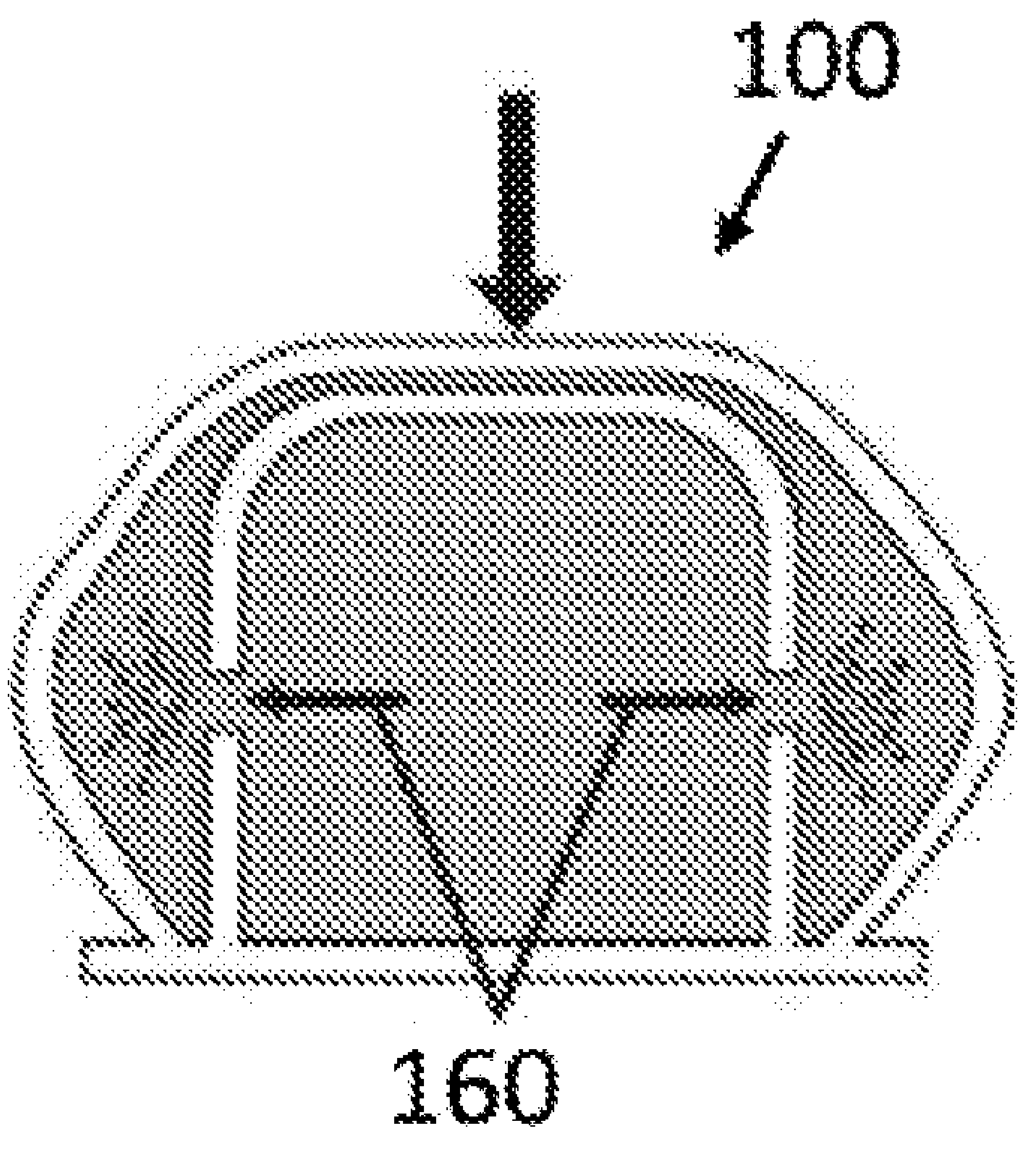
Primary Examiner — Tan Le
(74) *Attorney, Agent, or Firm* — LUMEN PATENT FIRM

(57) **ABSTRACT**

Devices, systems, and methods for shock absorption are provided herein. Collapsible shock absorption devices have an inner wall having at least one orifice, an outer wall, and a fluid sealed within the outer wall can mitigate sharp increases in force during loading and can better distribute loading forces. In some cases, collapsible shock absorption devices disclosed herein are used for prevention of injury to a biological tissue of a subject or damage to an inanimate object.

15 Claims, 26 Drawing Sheets





(56) References Cited

U.S. PATENT DOCUMENTS

8,950,735	B2	2/2015	Reynolds	
2009/0265839	A1	10/2009	Young	
2012/0151664	A1 *	6/2012	Kirshon	A42B 3/12 2/413
2014/0007322	A1	1/2014	Marz	
2014/0137437	A1	5/2014	Nakano	
2014/0208486	A1	7/2014	Krueger	
2018/0343952	A1	12/2018	Lachance	
2019/0154101	A1	5/2019	McDonnell	
2019/0350298	A1 *	11/2019	Hoshizaki	A42B 3/12
2020/0046056	A1	2/2020	Hawkes	

* cited by examiner

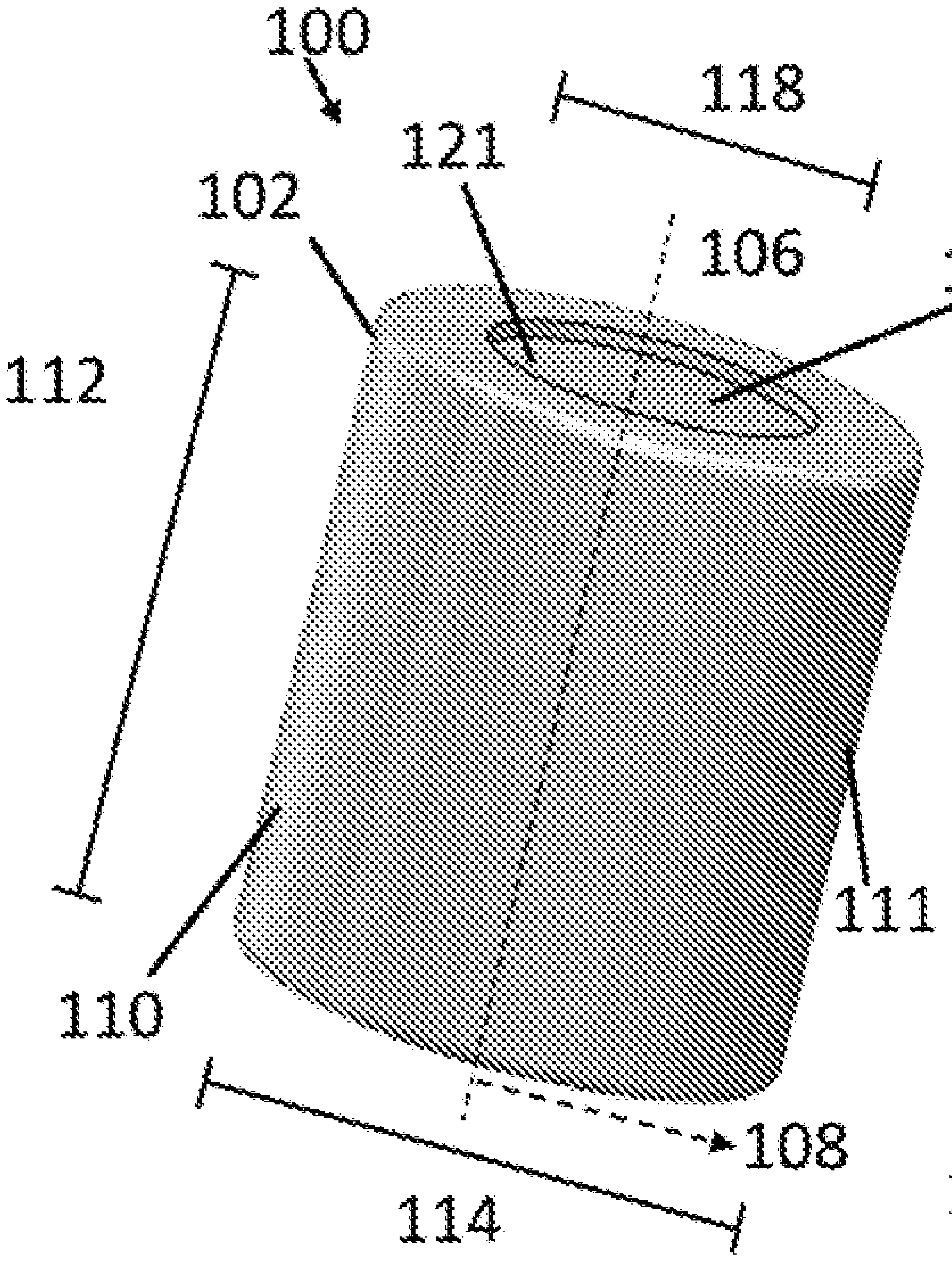

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FIG. 1A

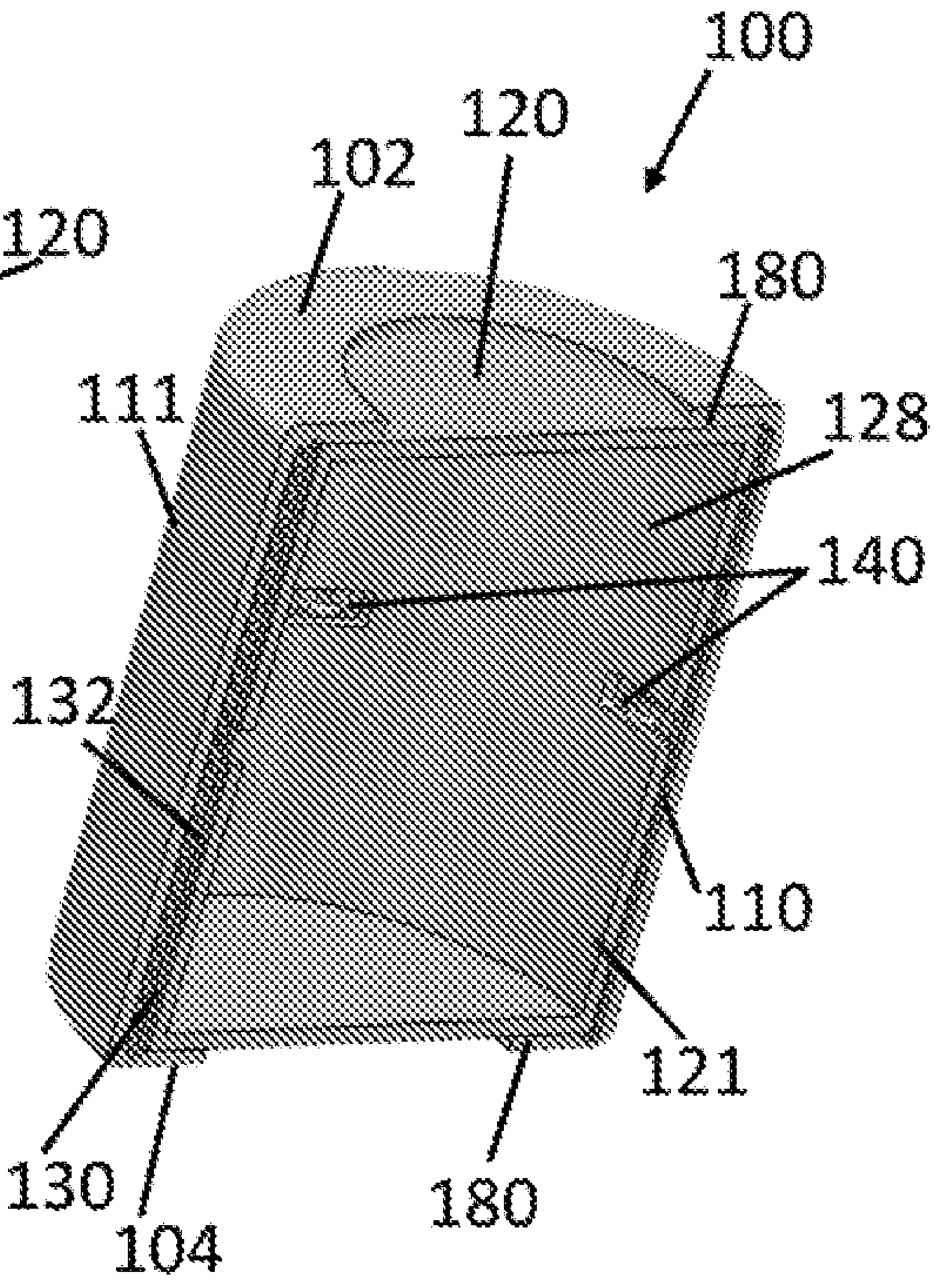
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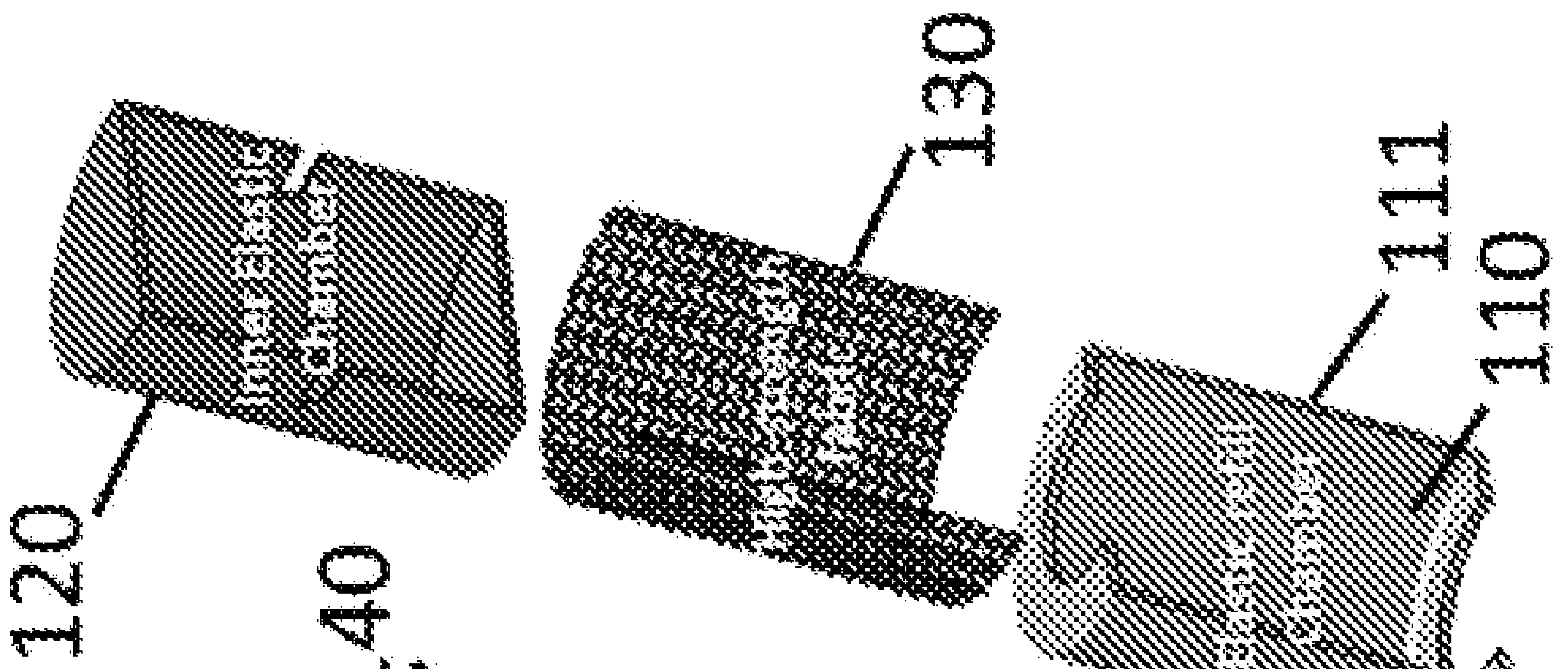
FIG. 1B



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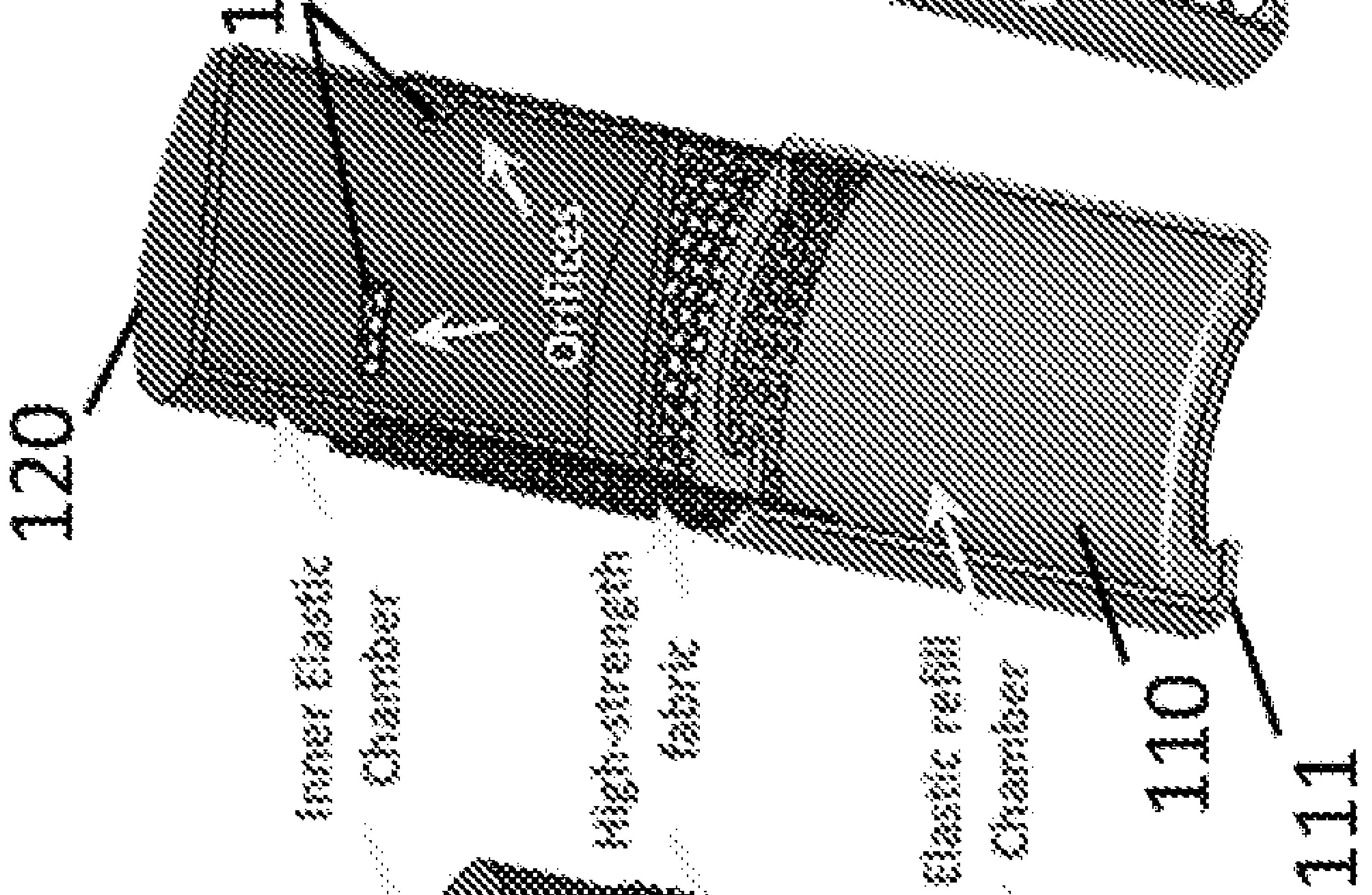

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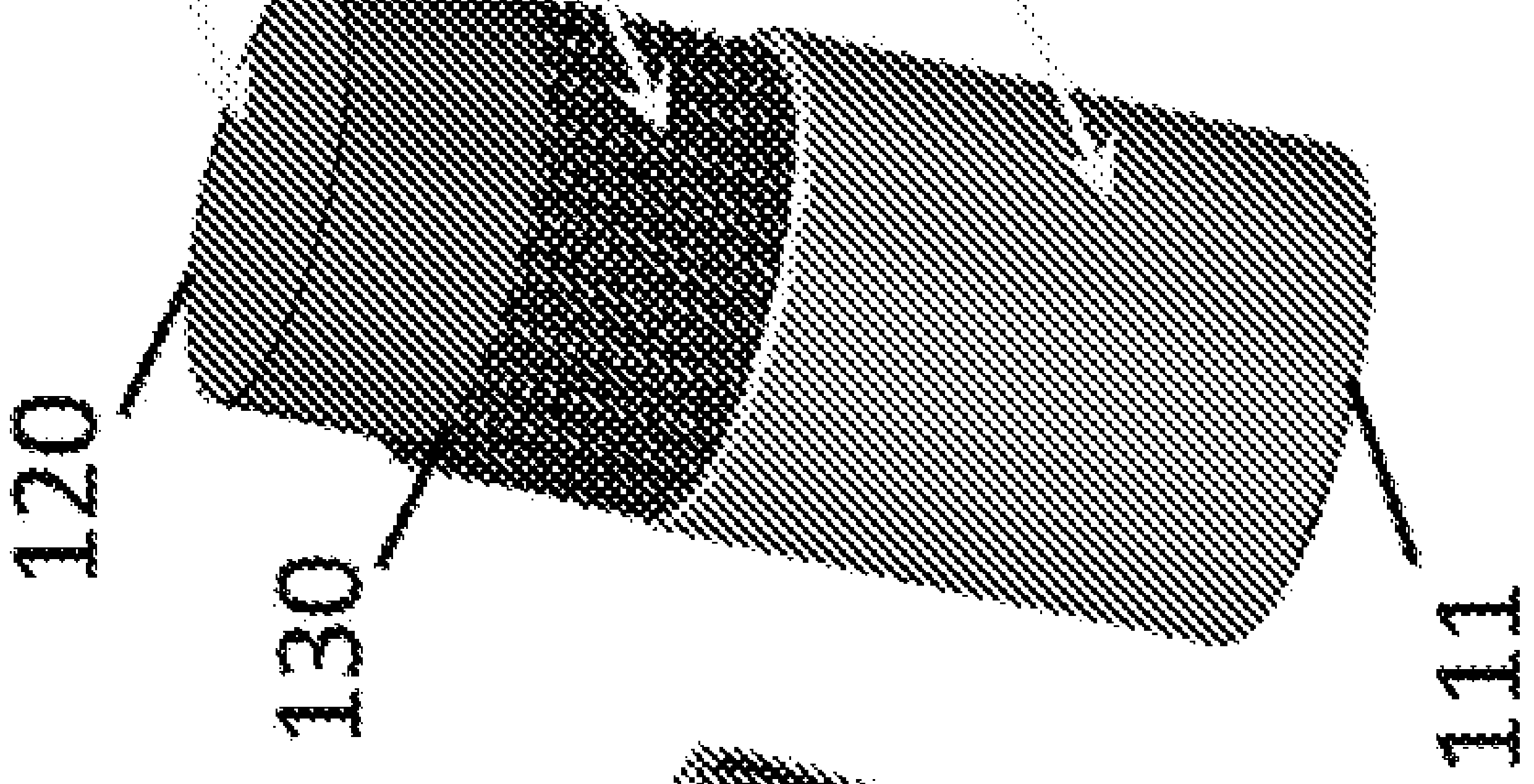


FIG. 2C

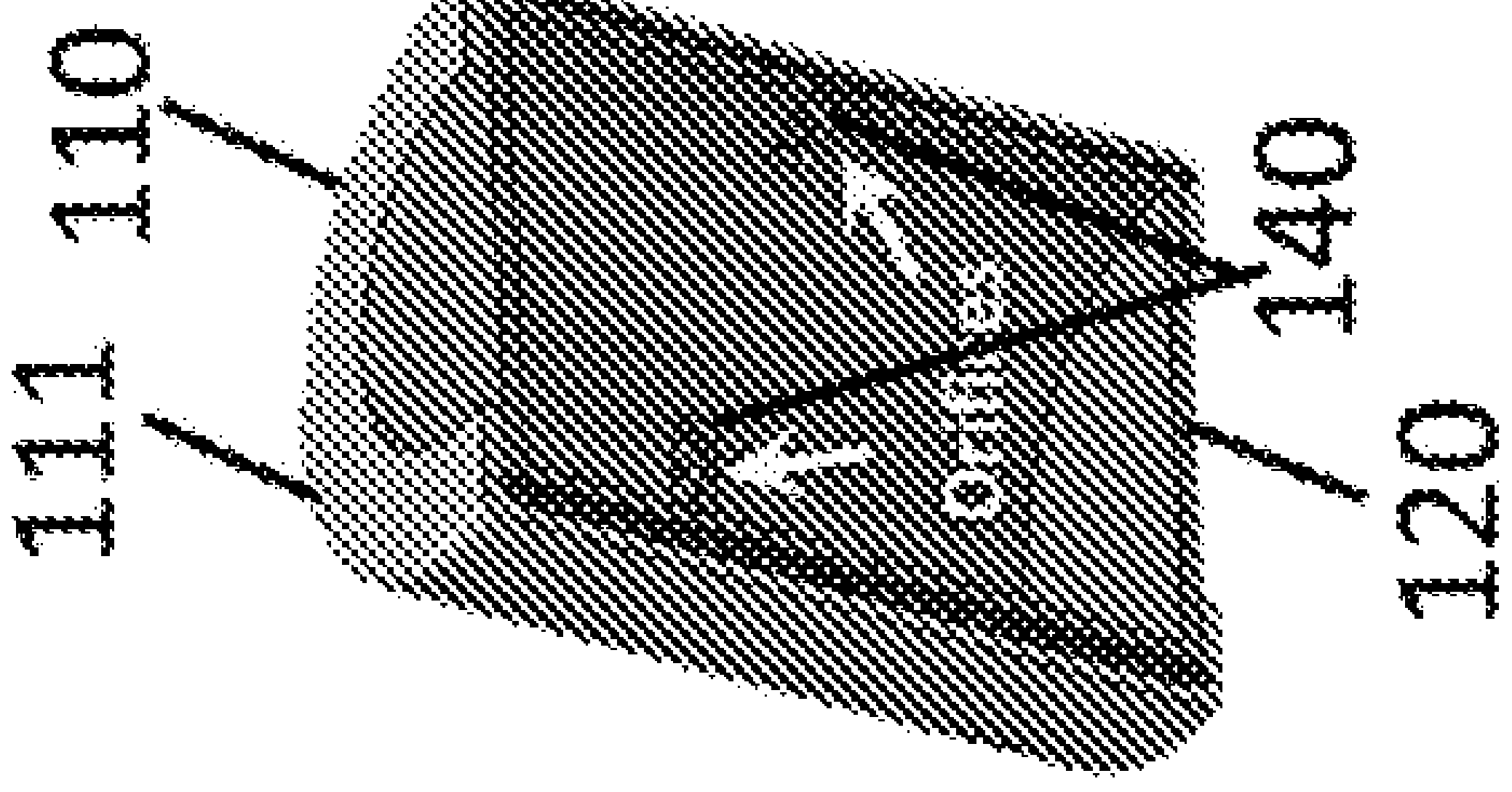
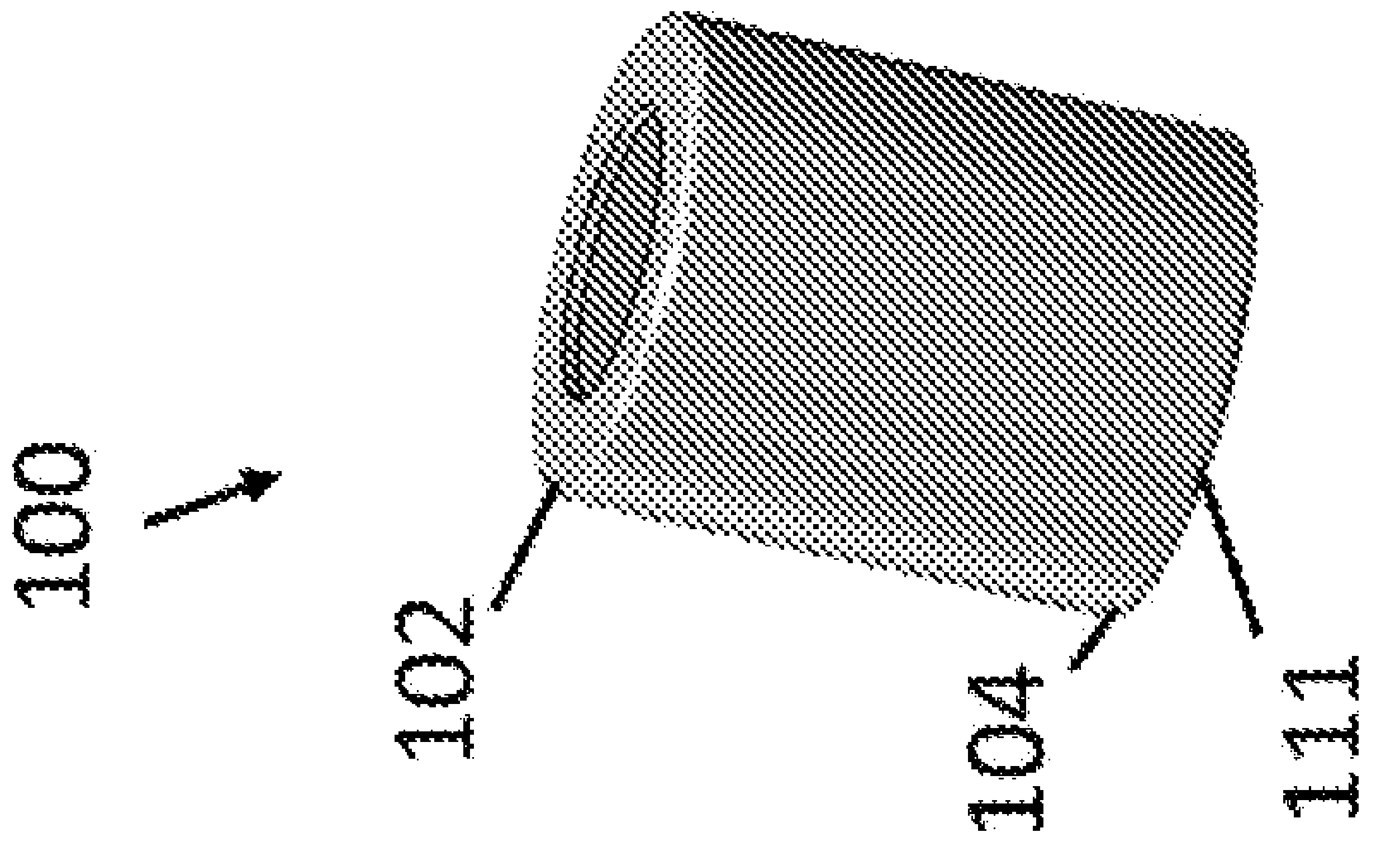


FIG. 2B



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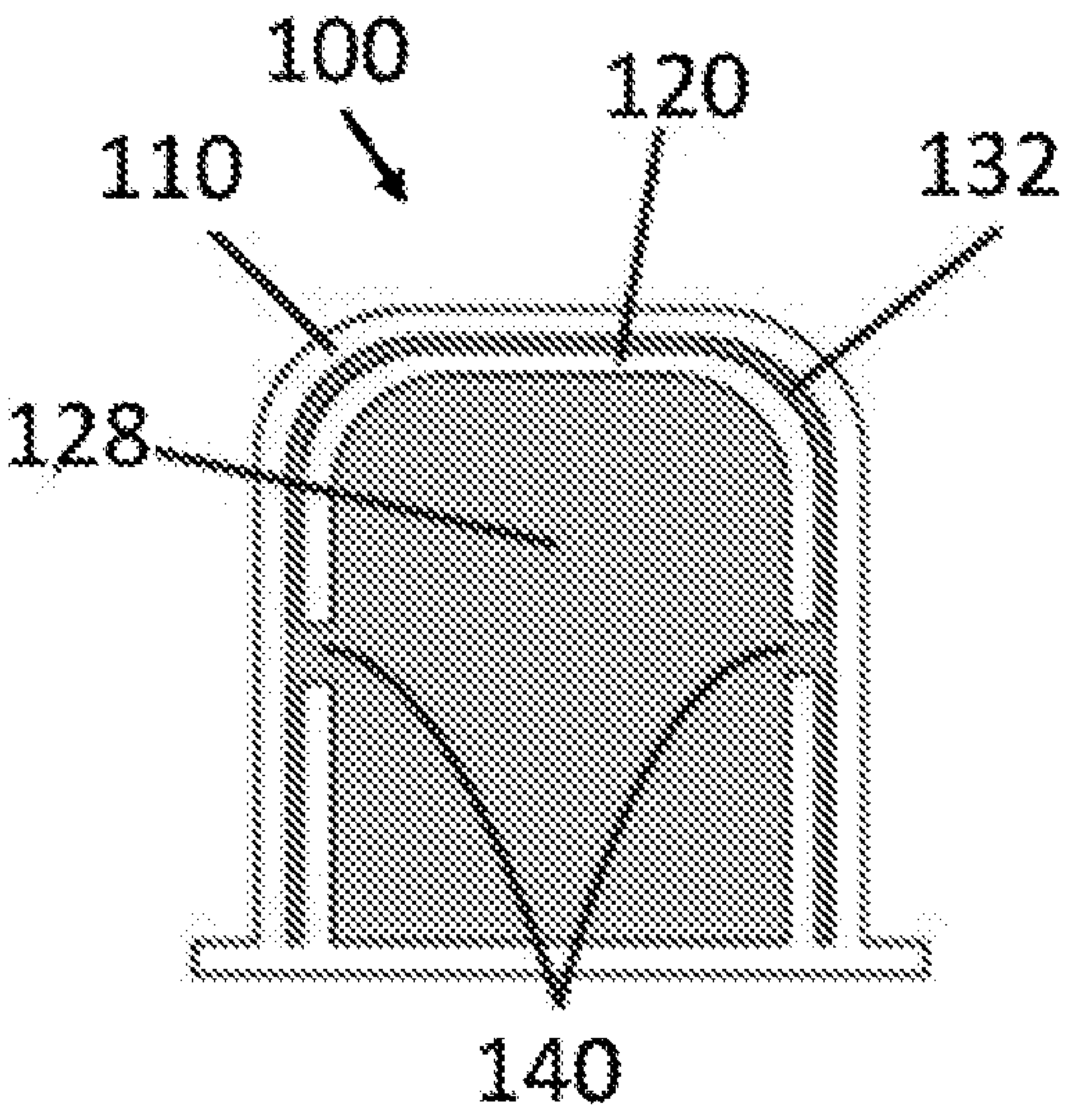

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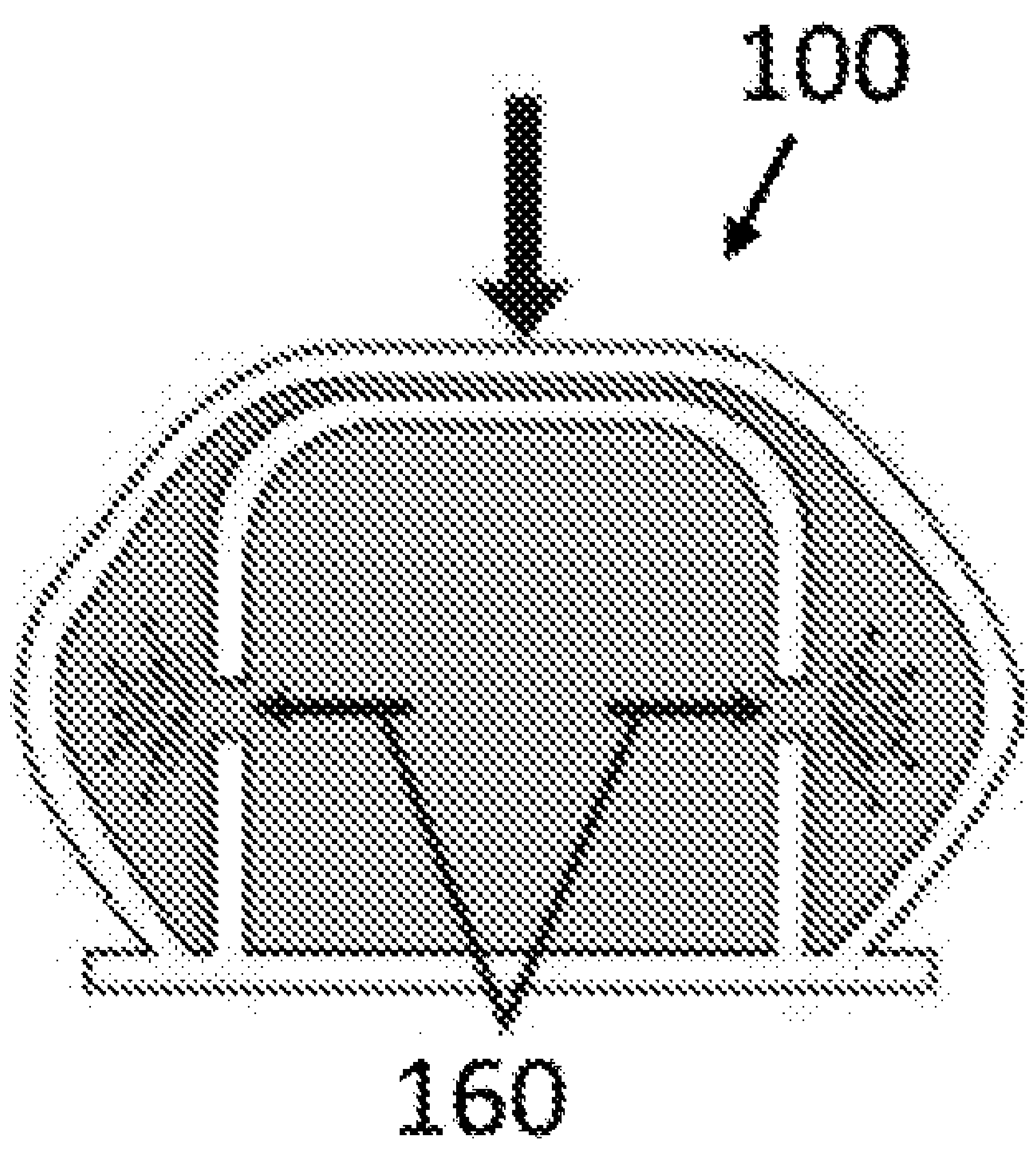

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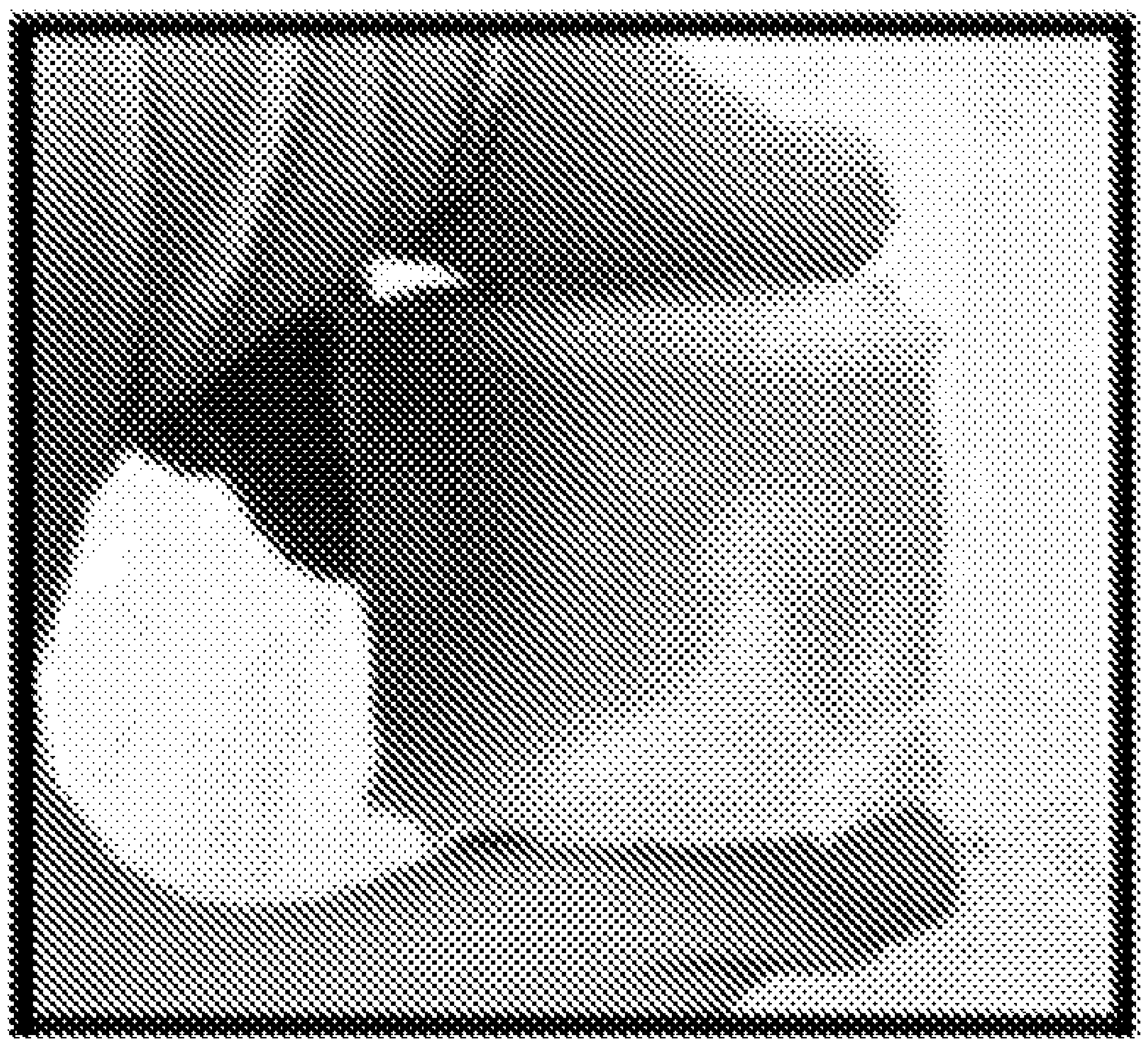

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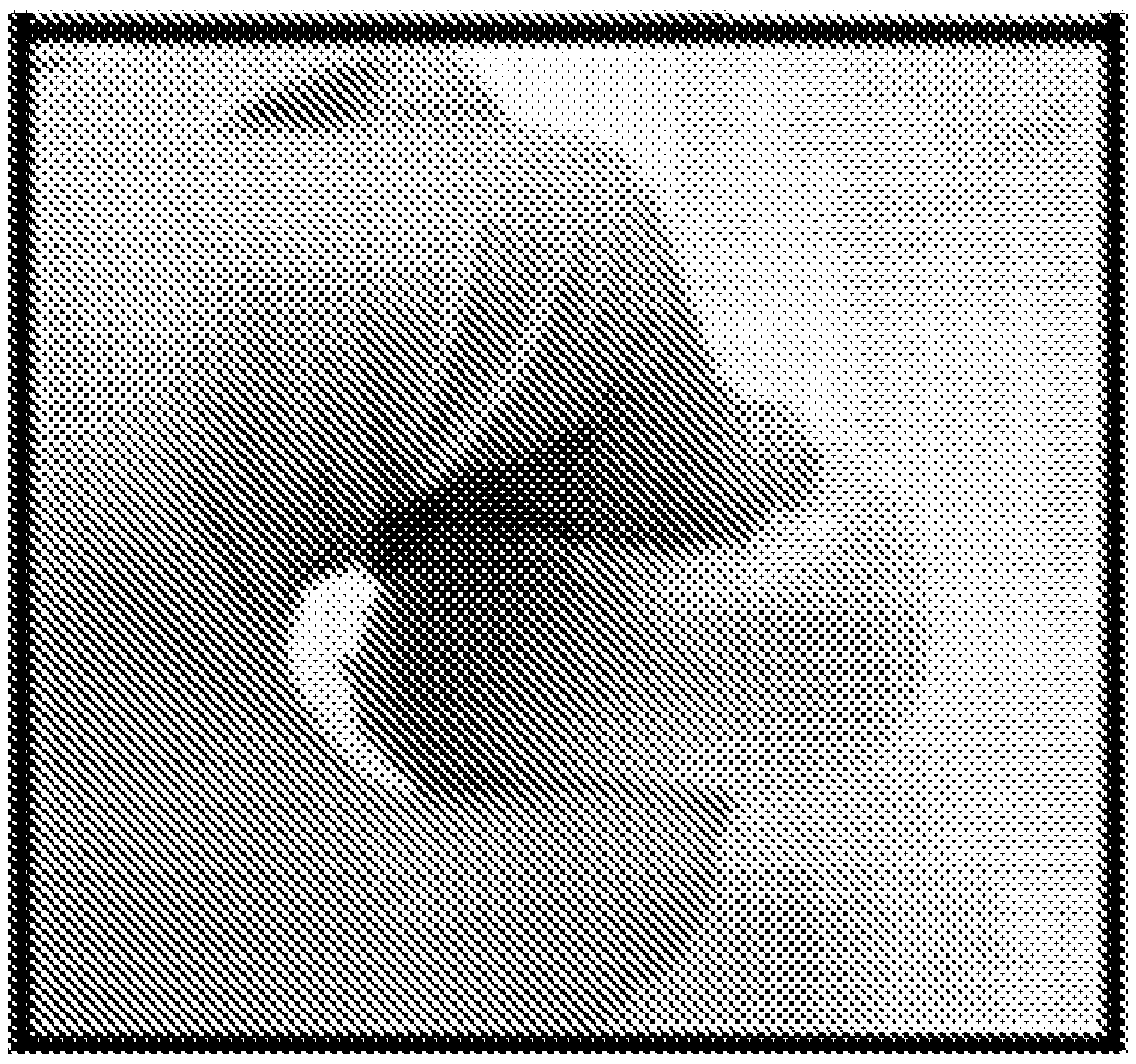

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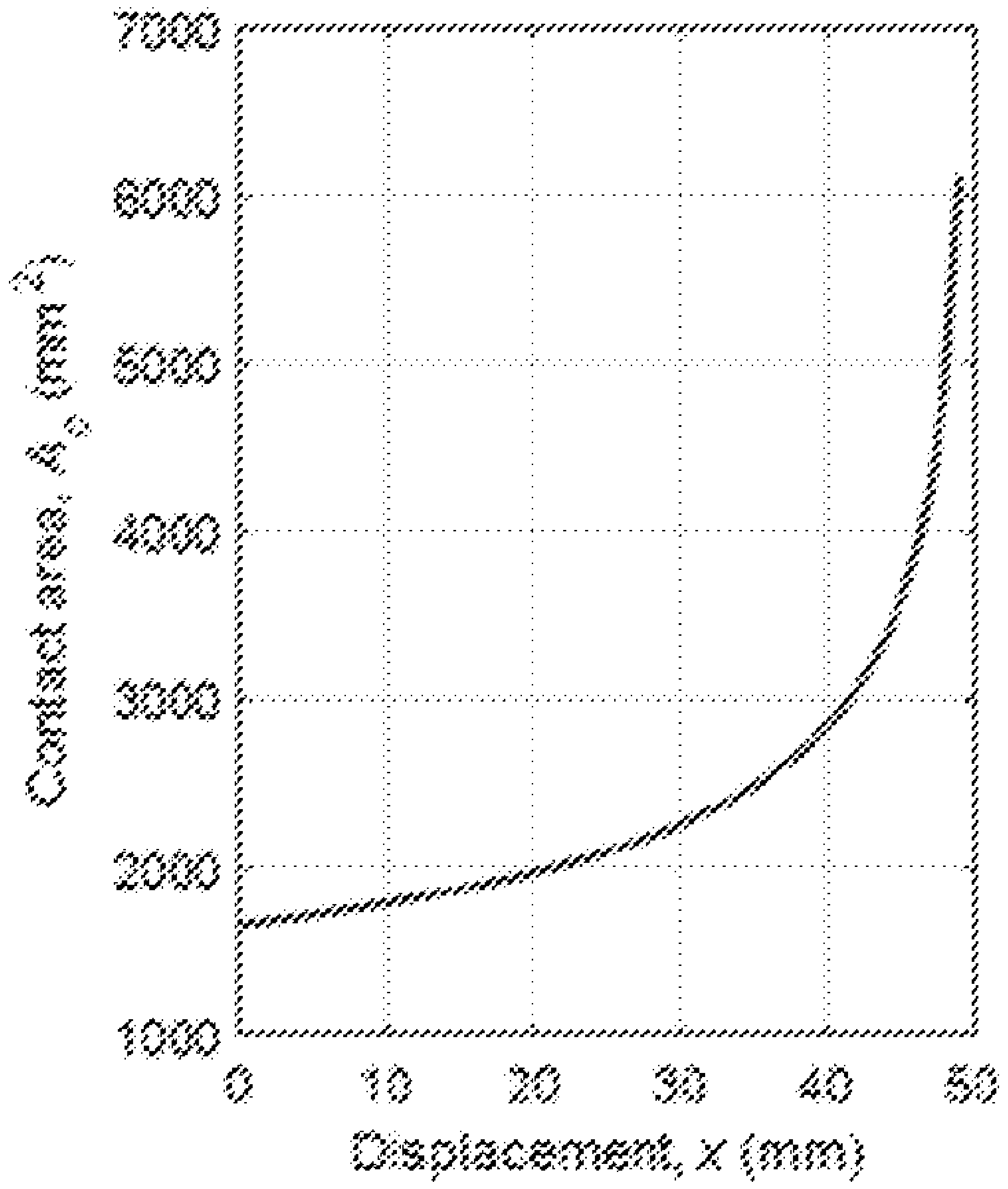

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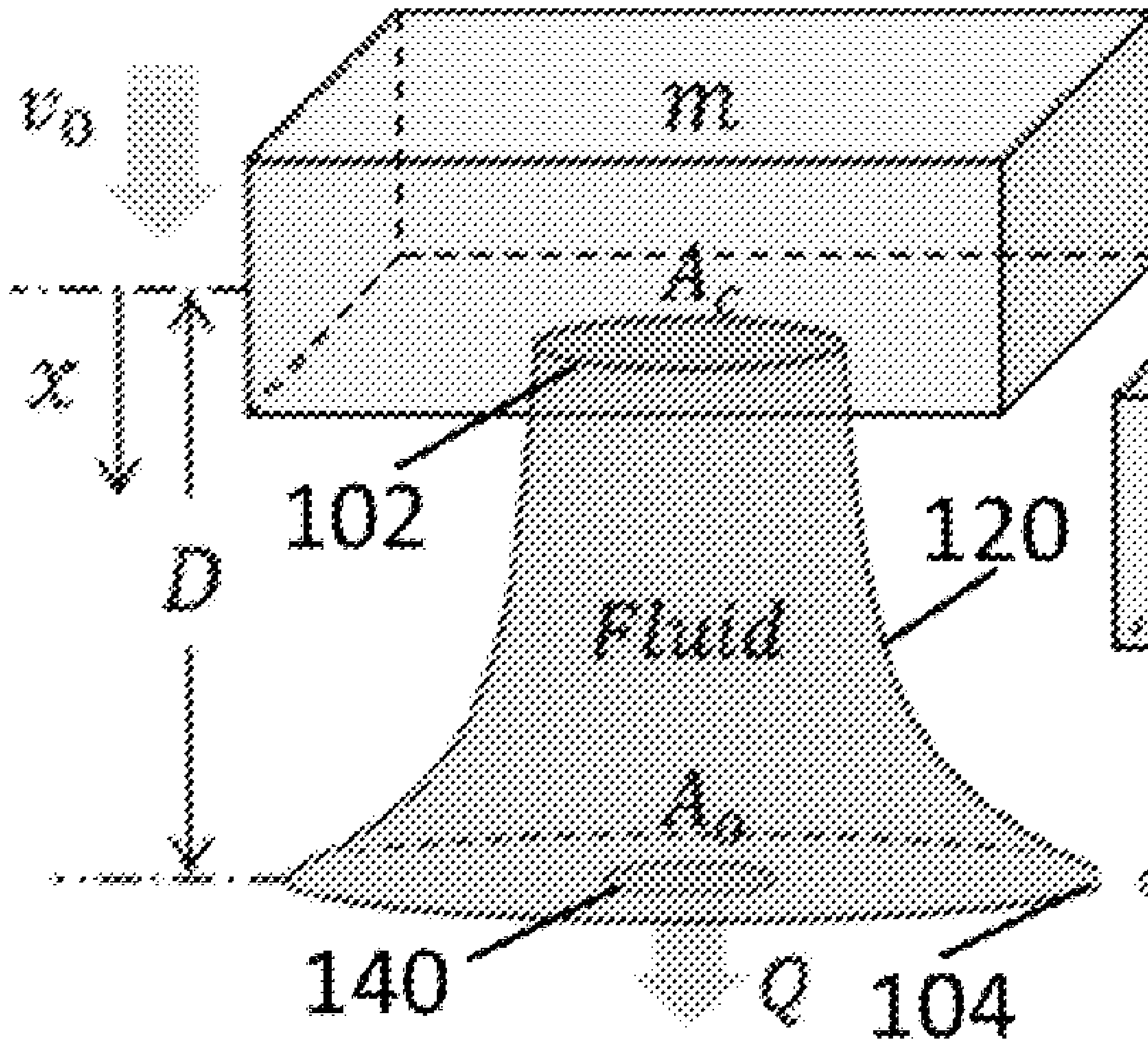

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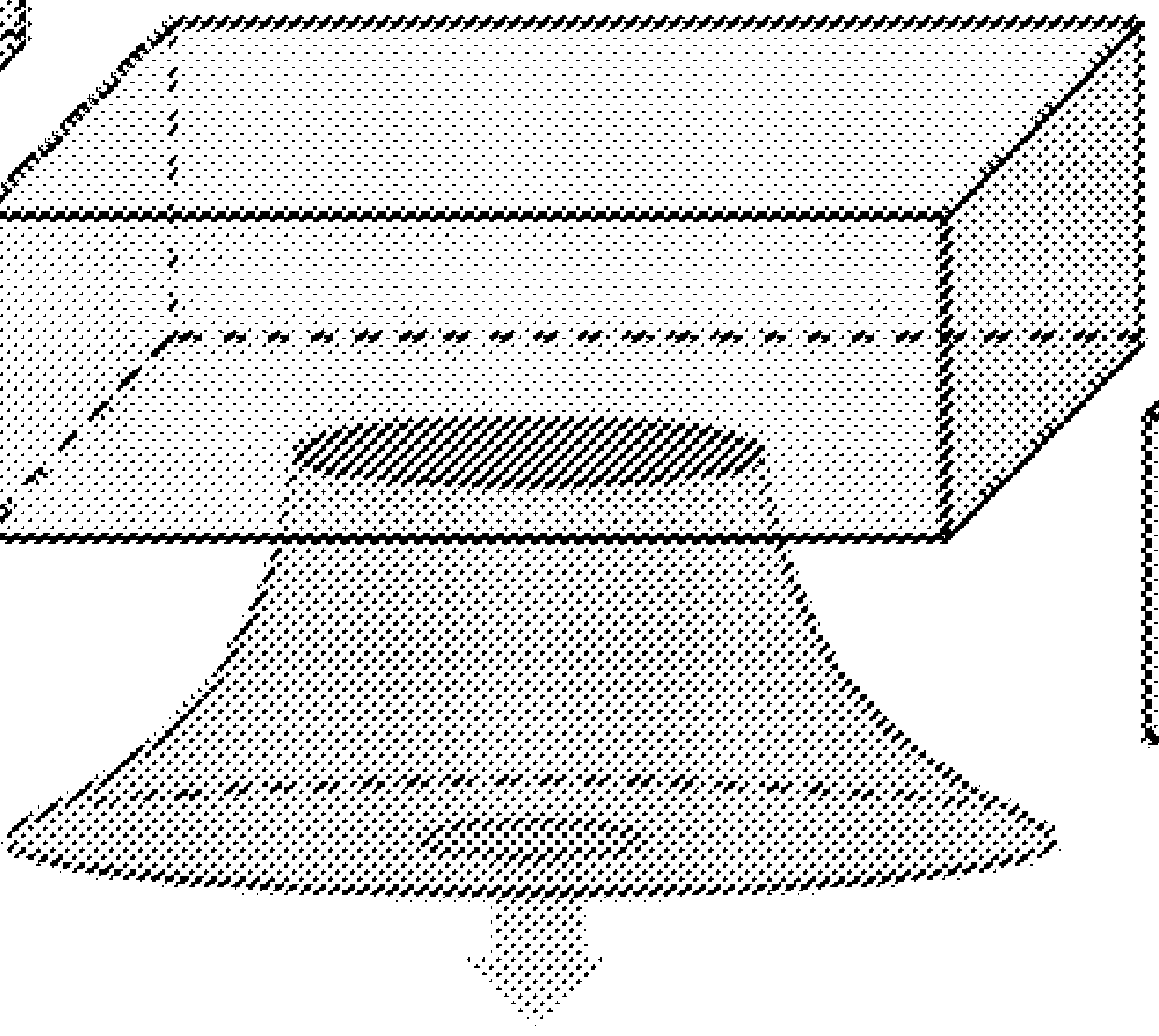

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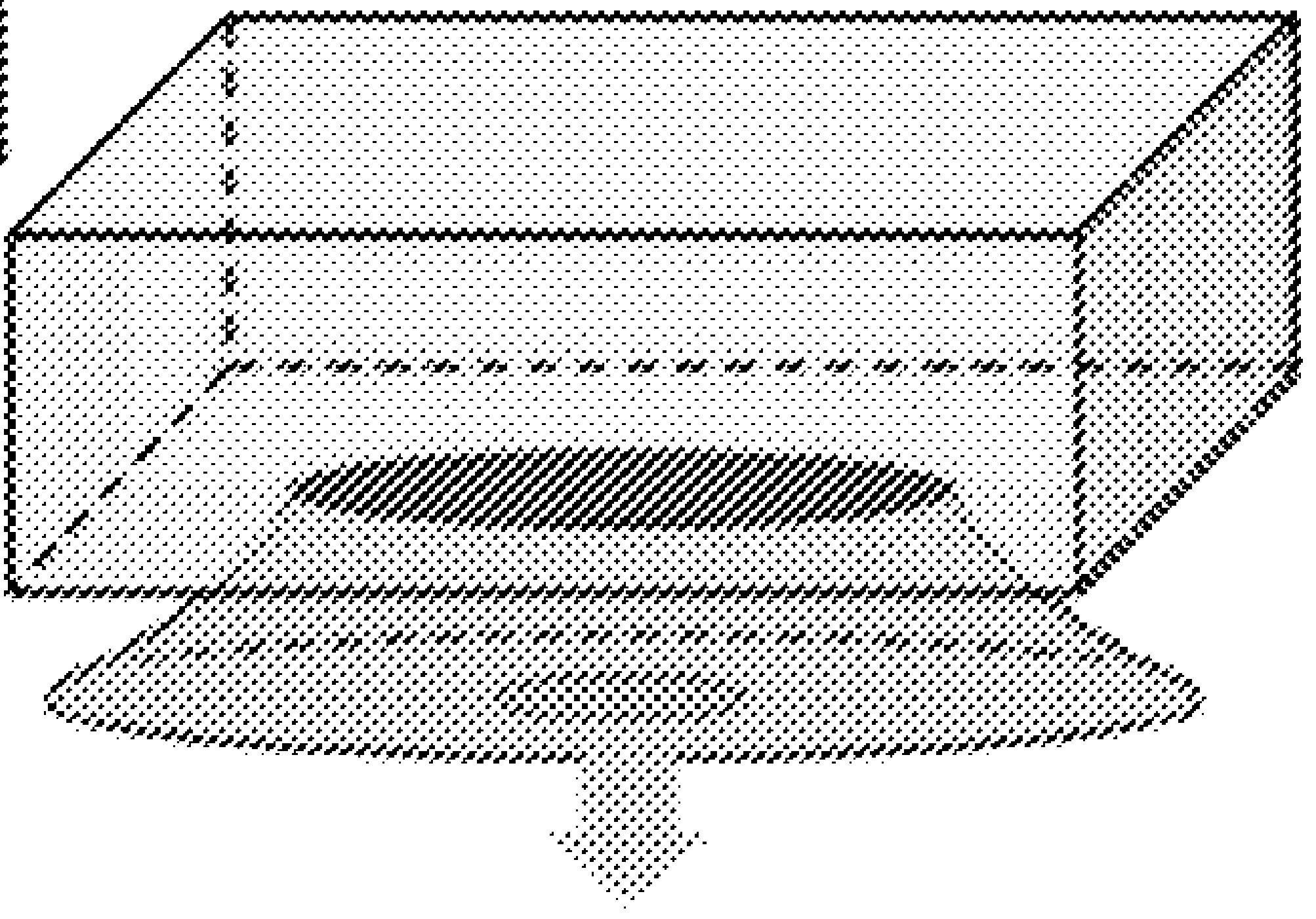

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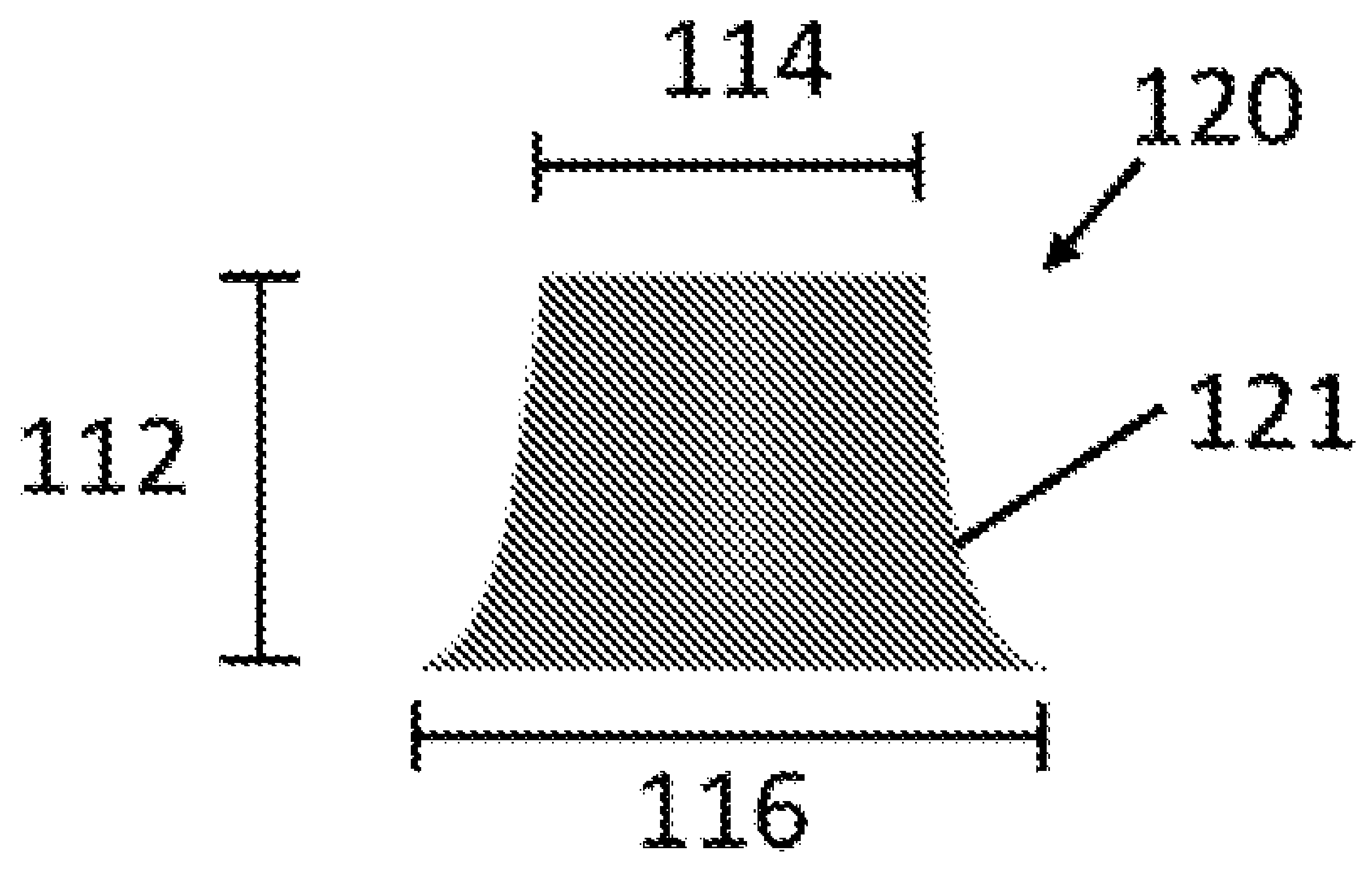

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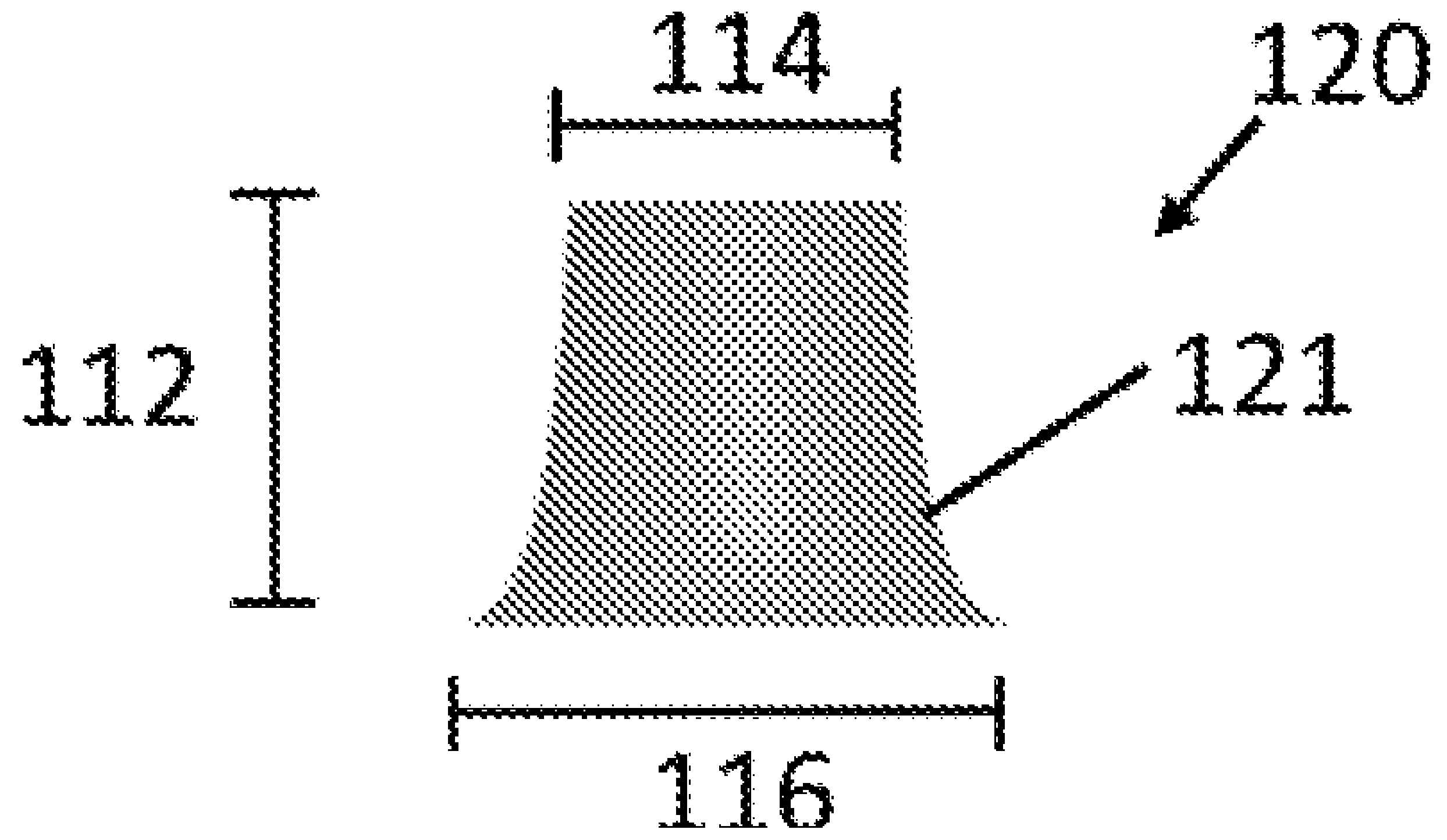

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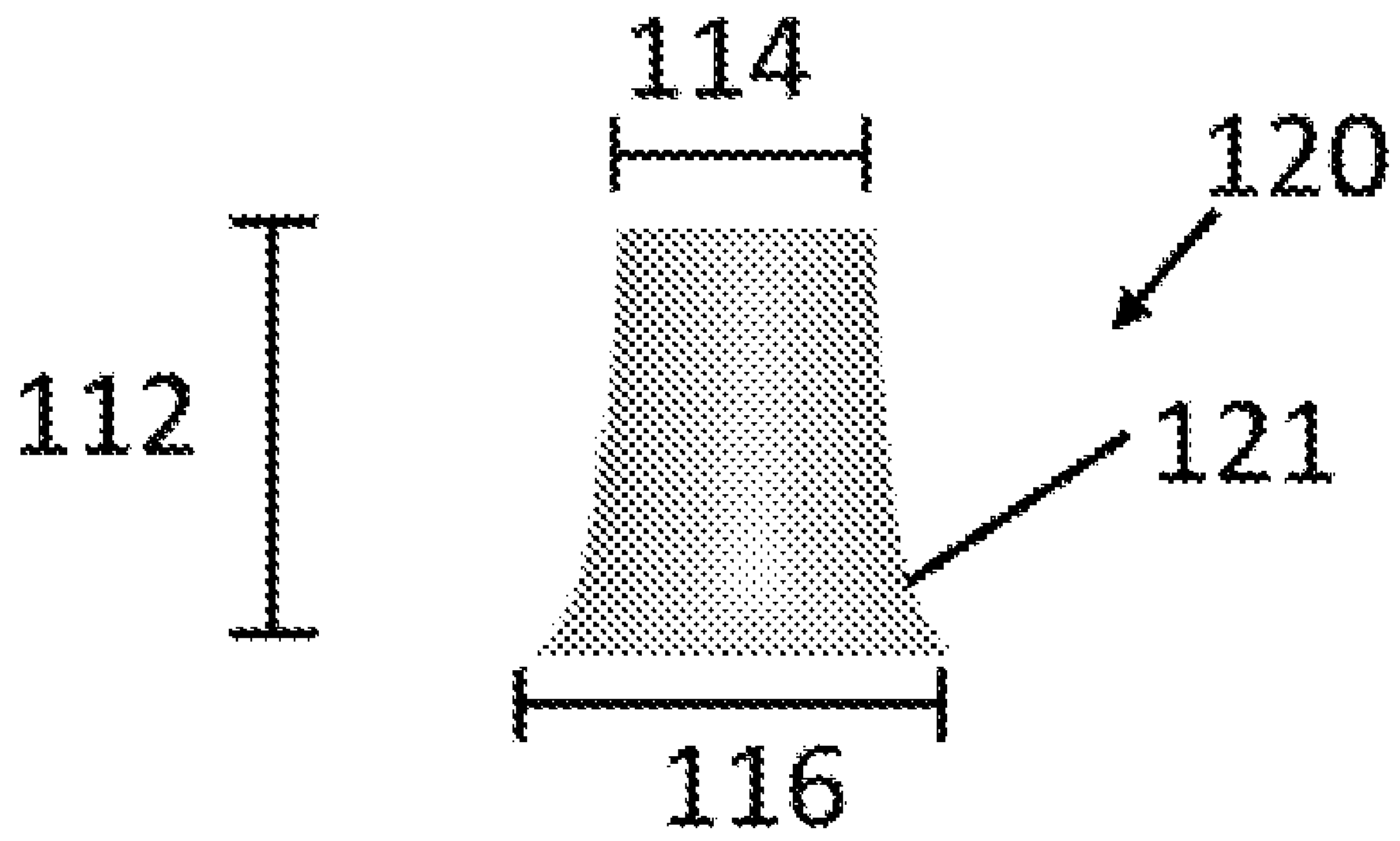

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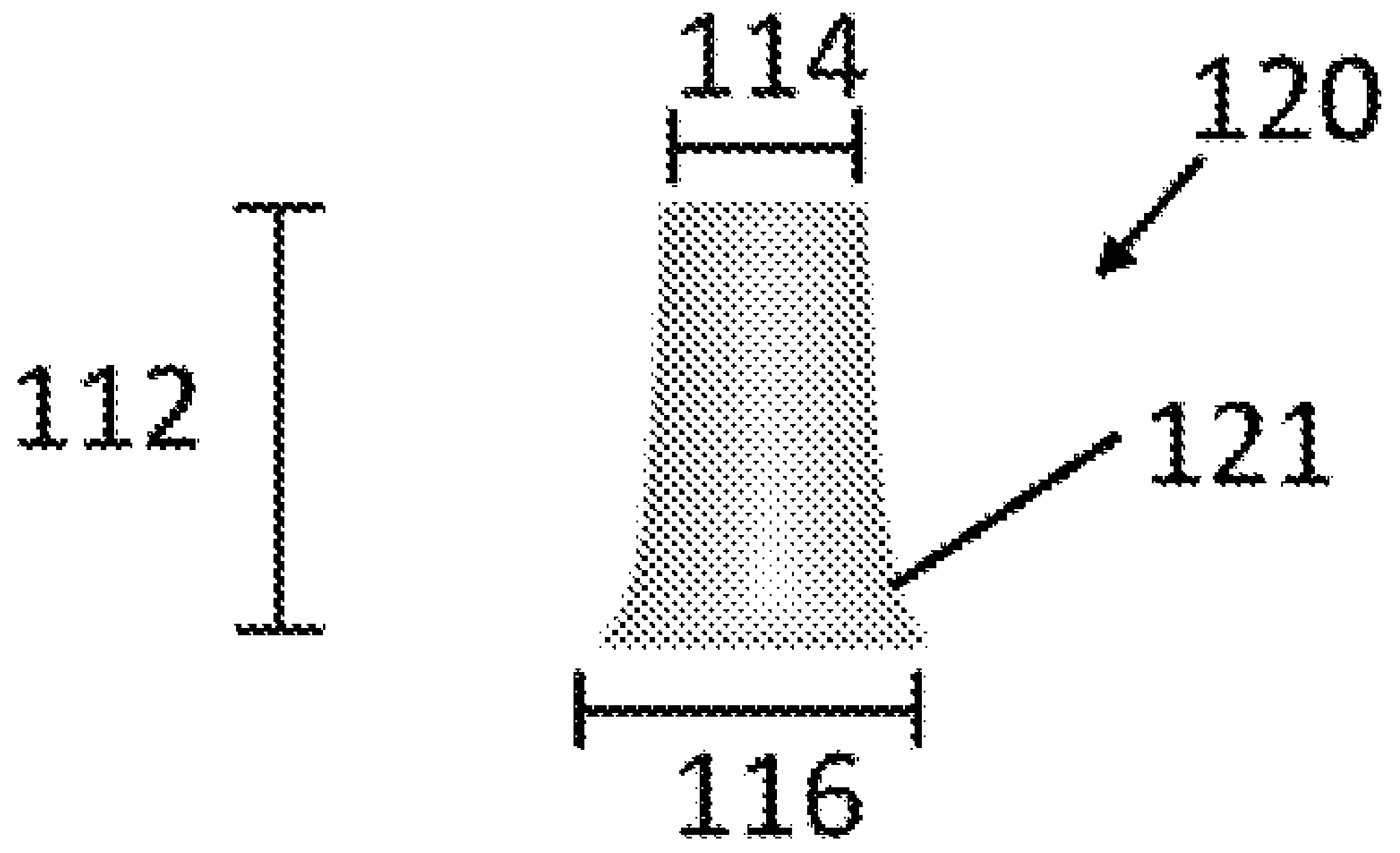

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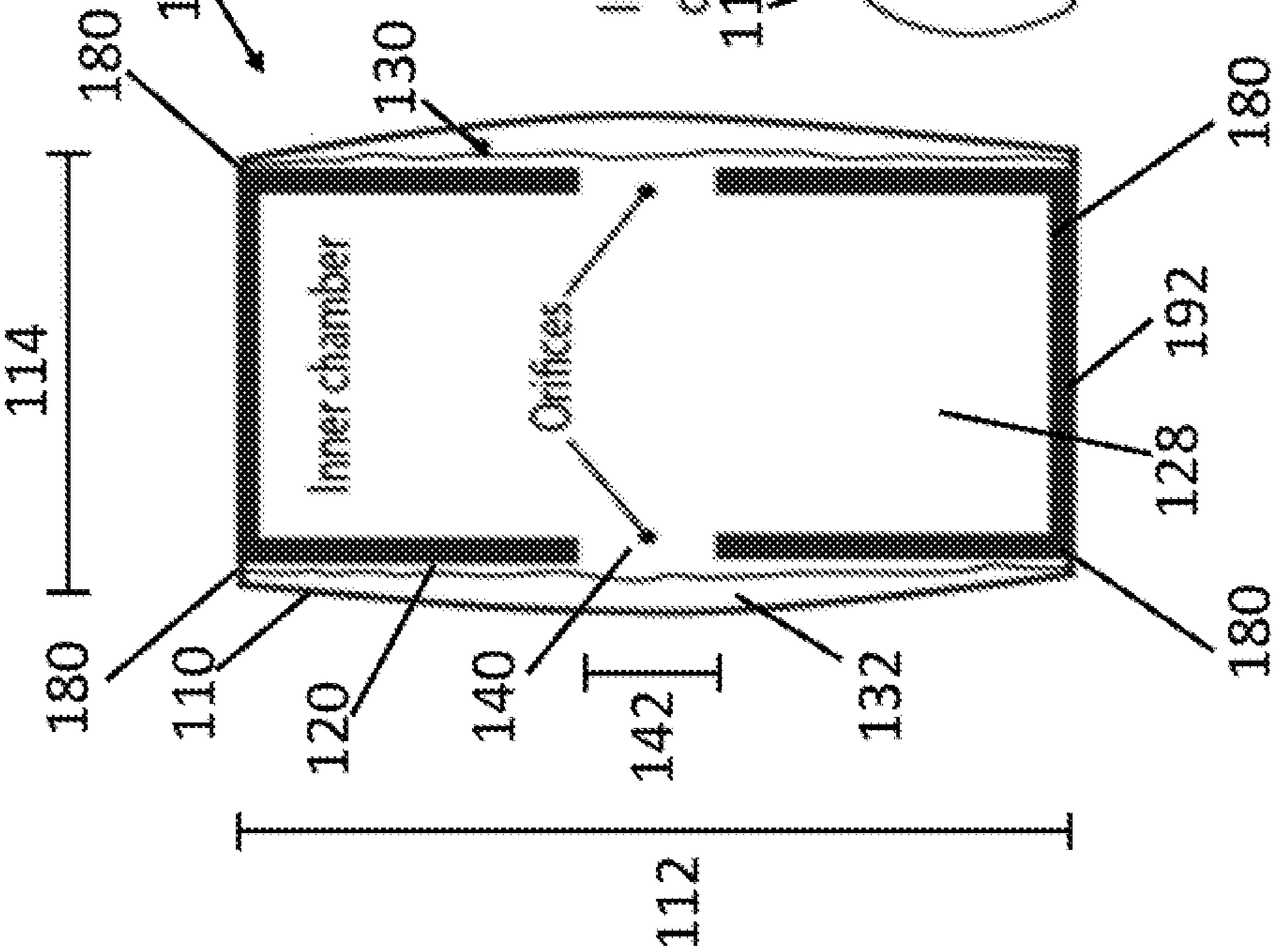
100
180
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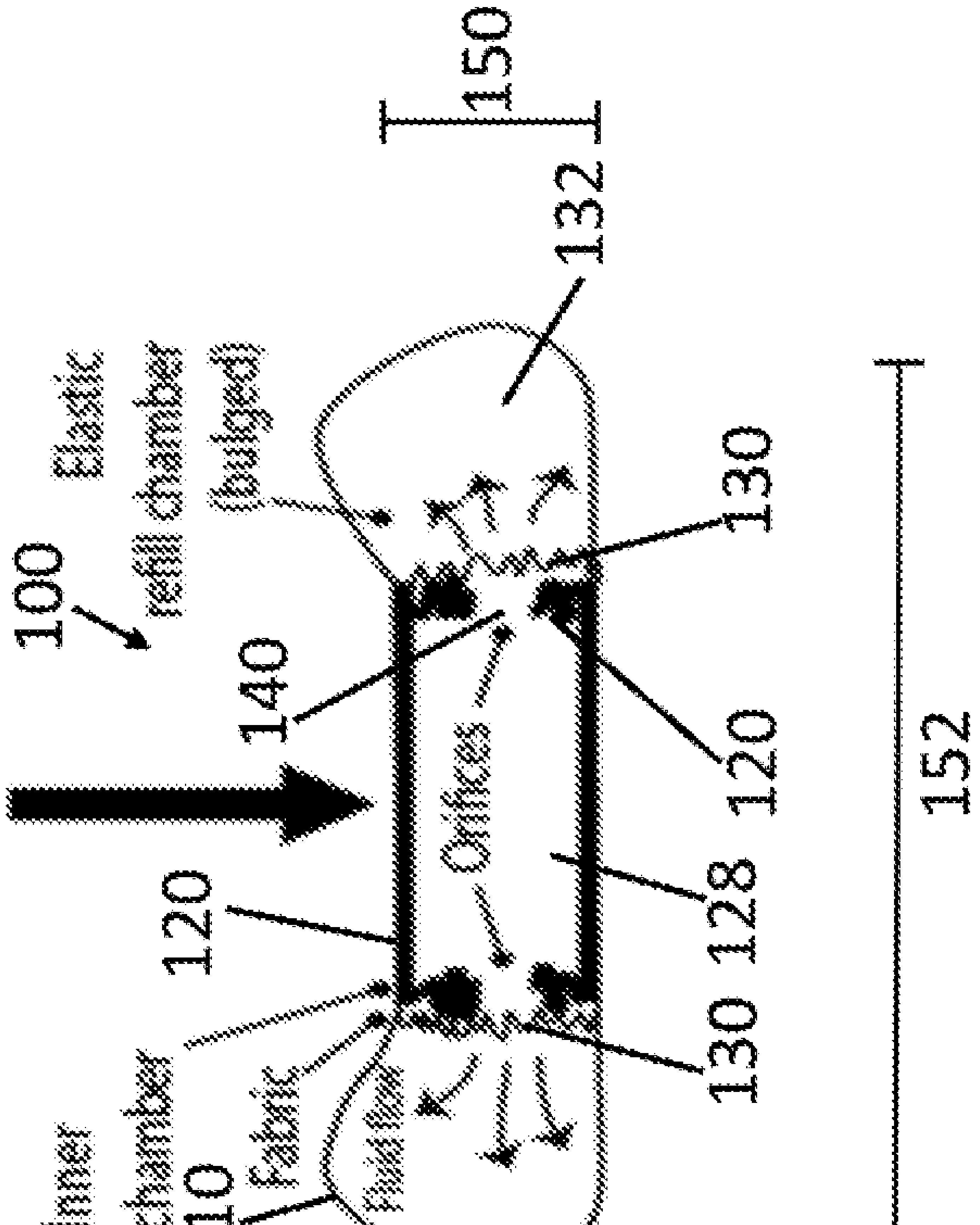
114
Inner chamber
Orifices
180
192
128
180
180
110
120
140
142
132
112

FIG. 6A


150
132
Elastic refill chamber (bulged)
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100
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Orifices
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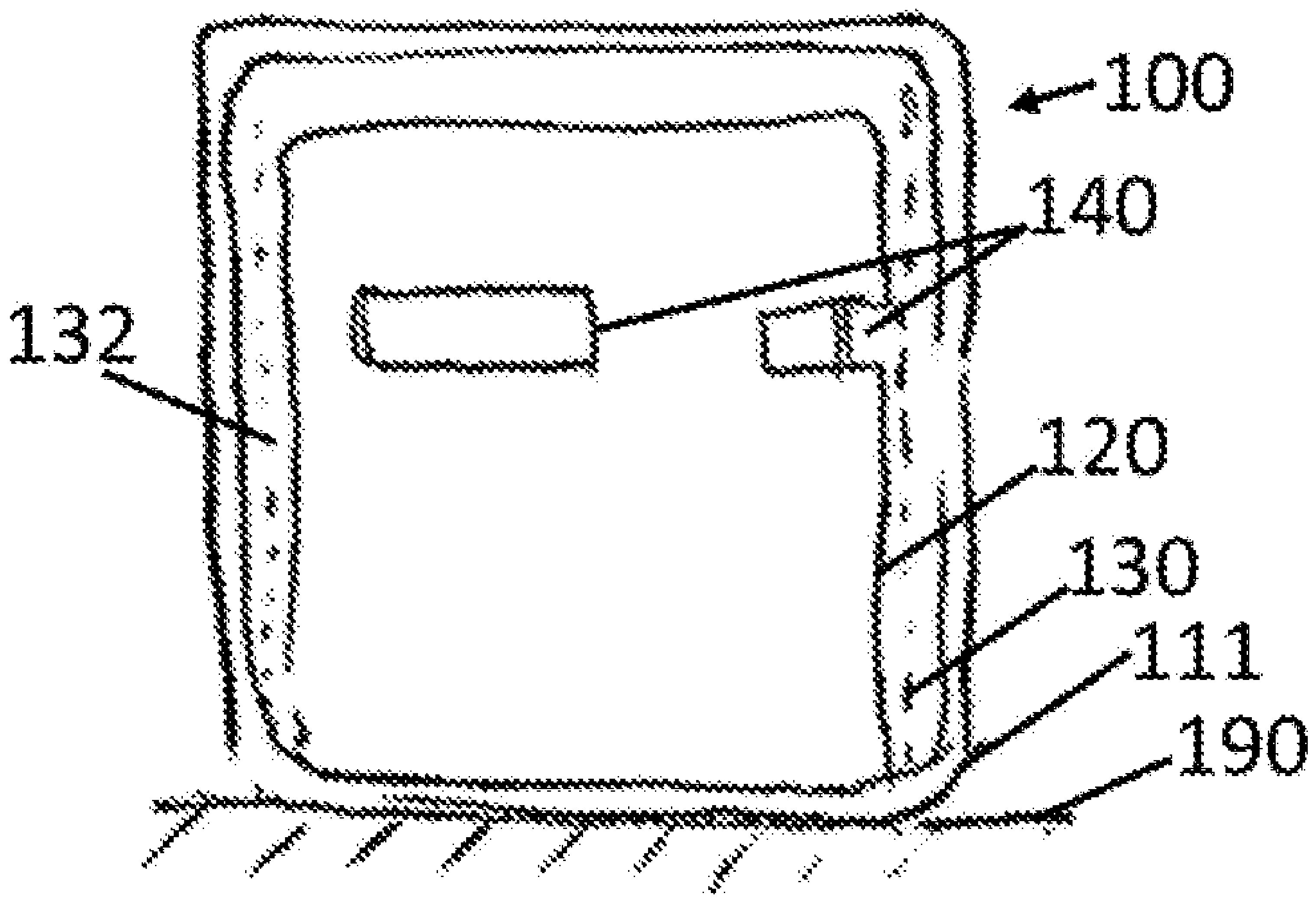
Inner chamber
Fabric
Fluid flow
110

FIG. 6B



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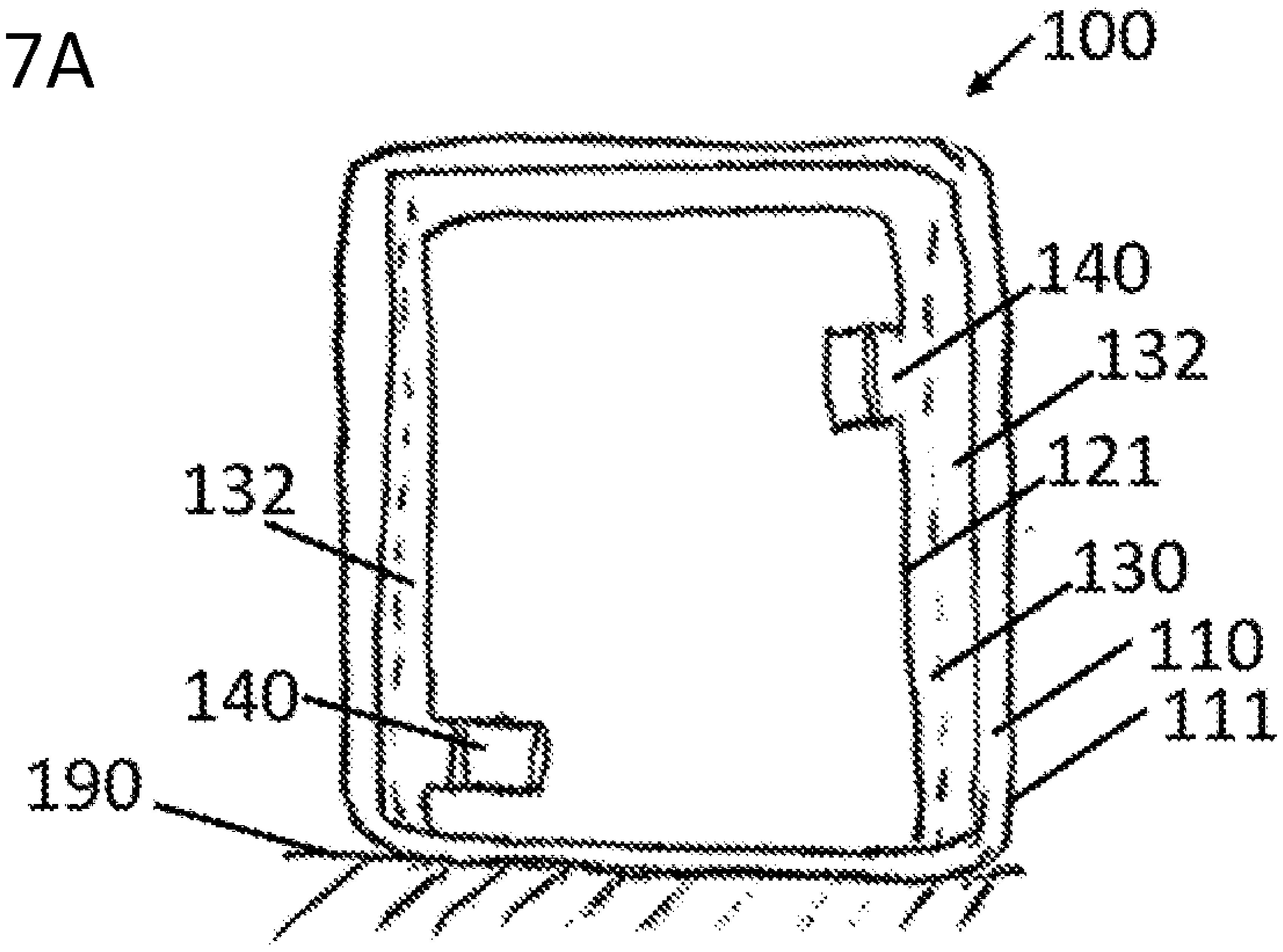

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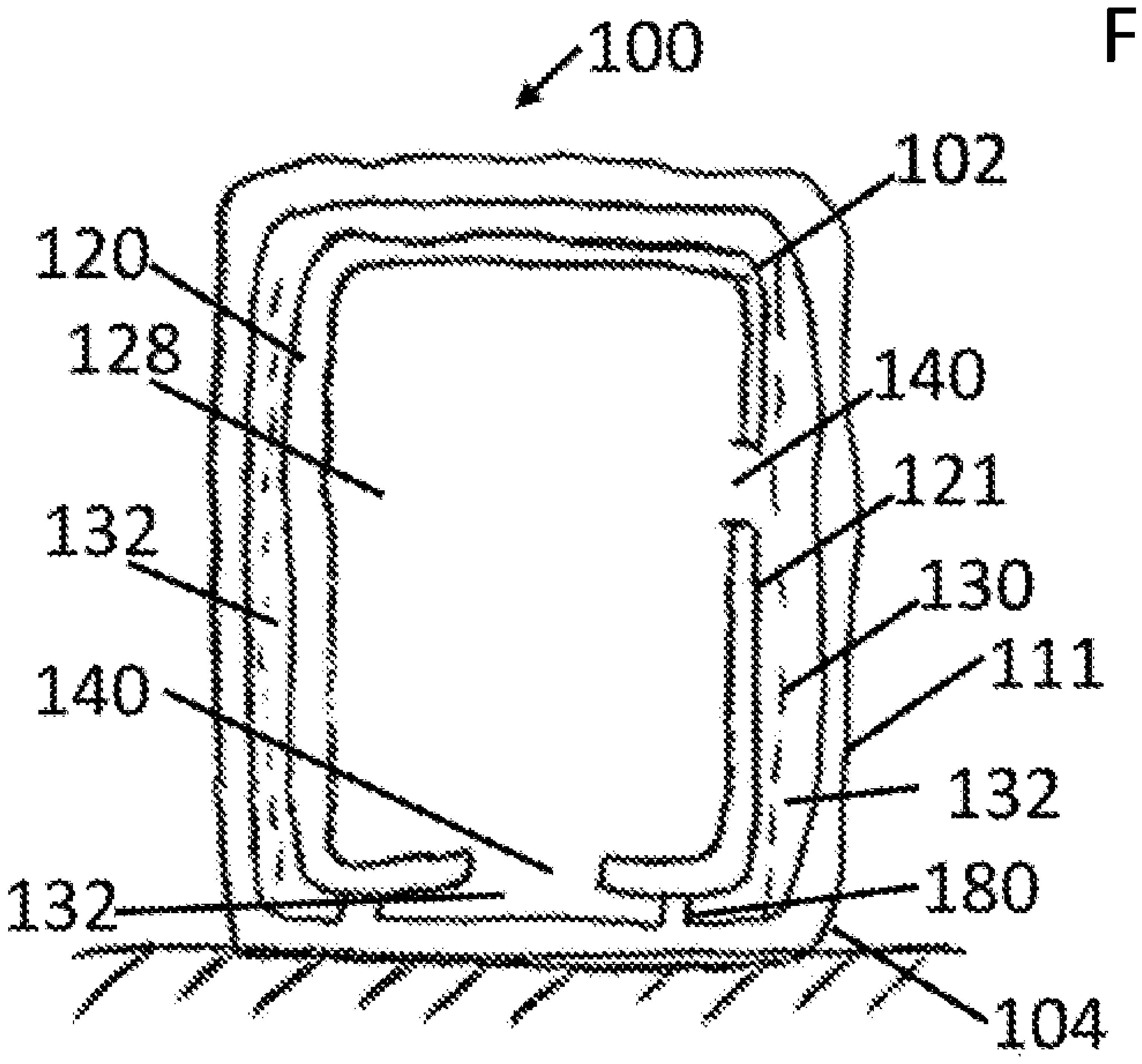

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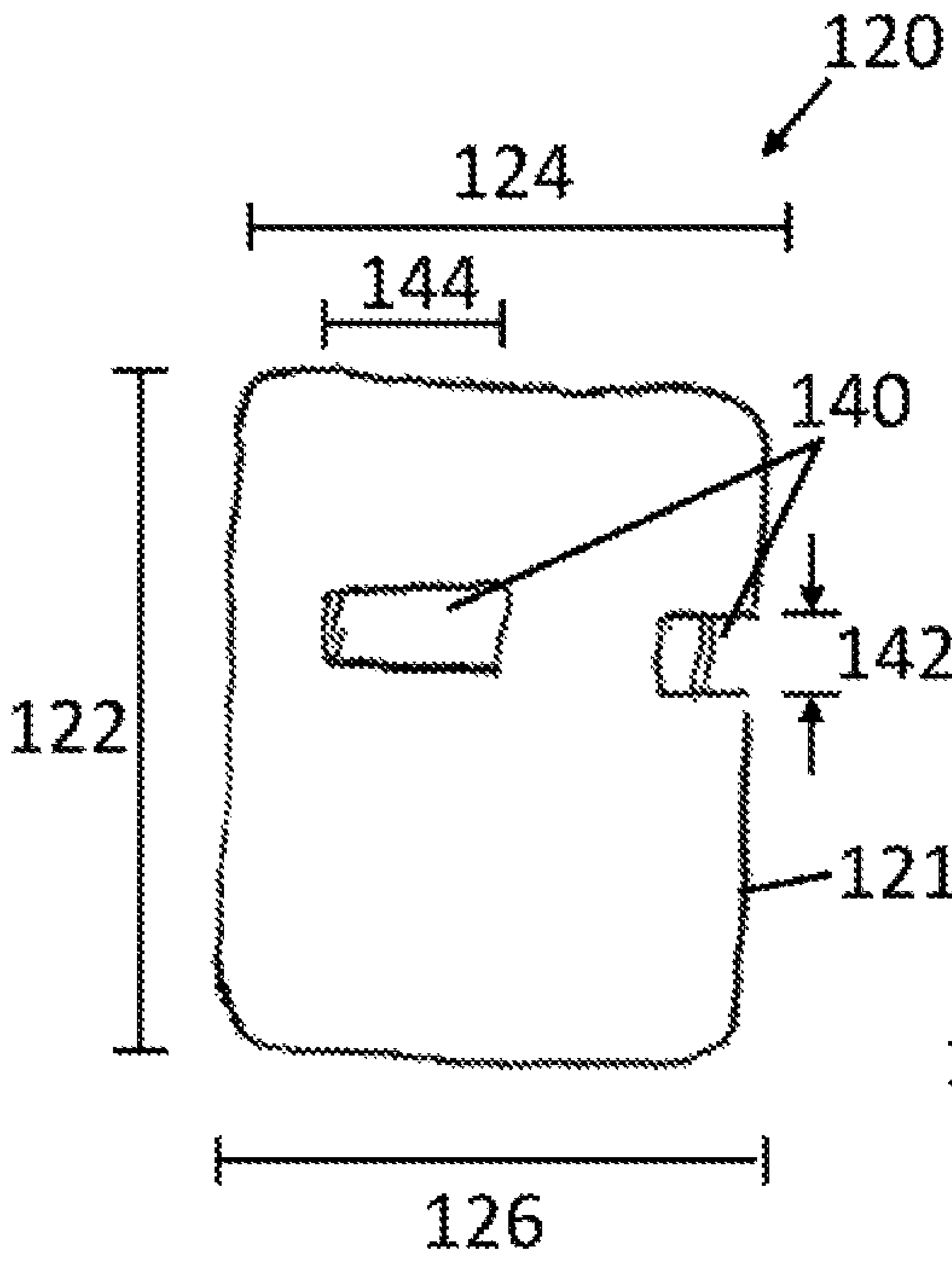

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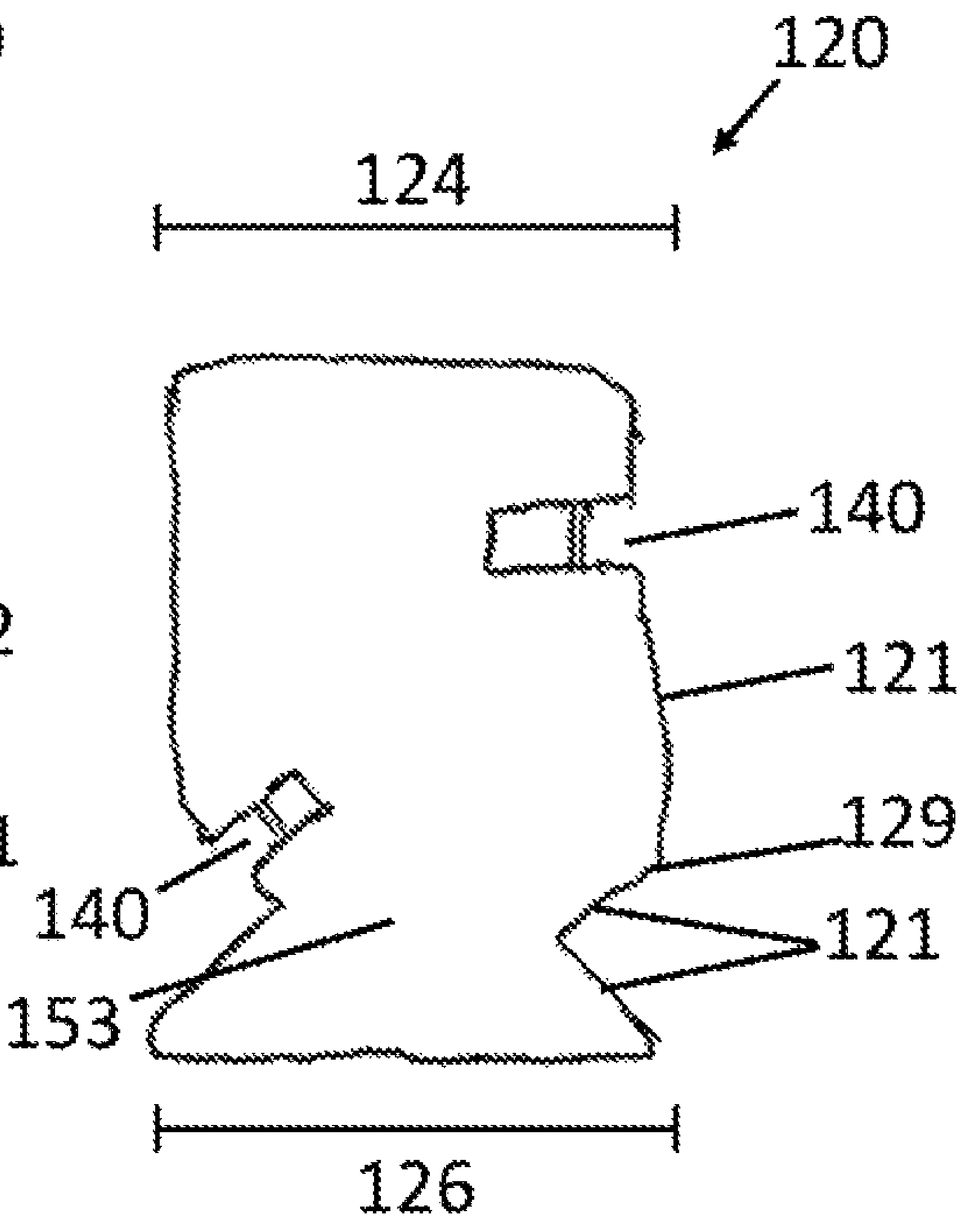

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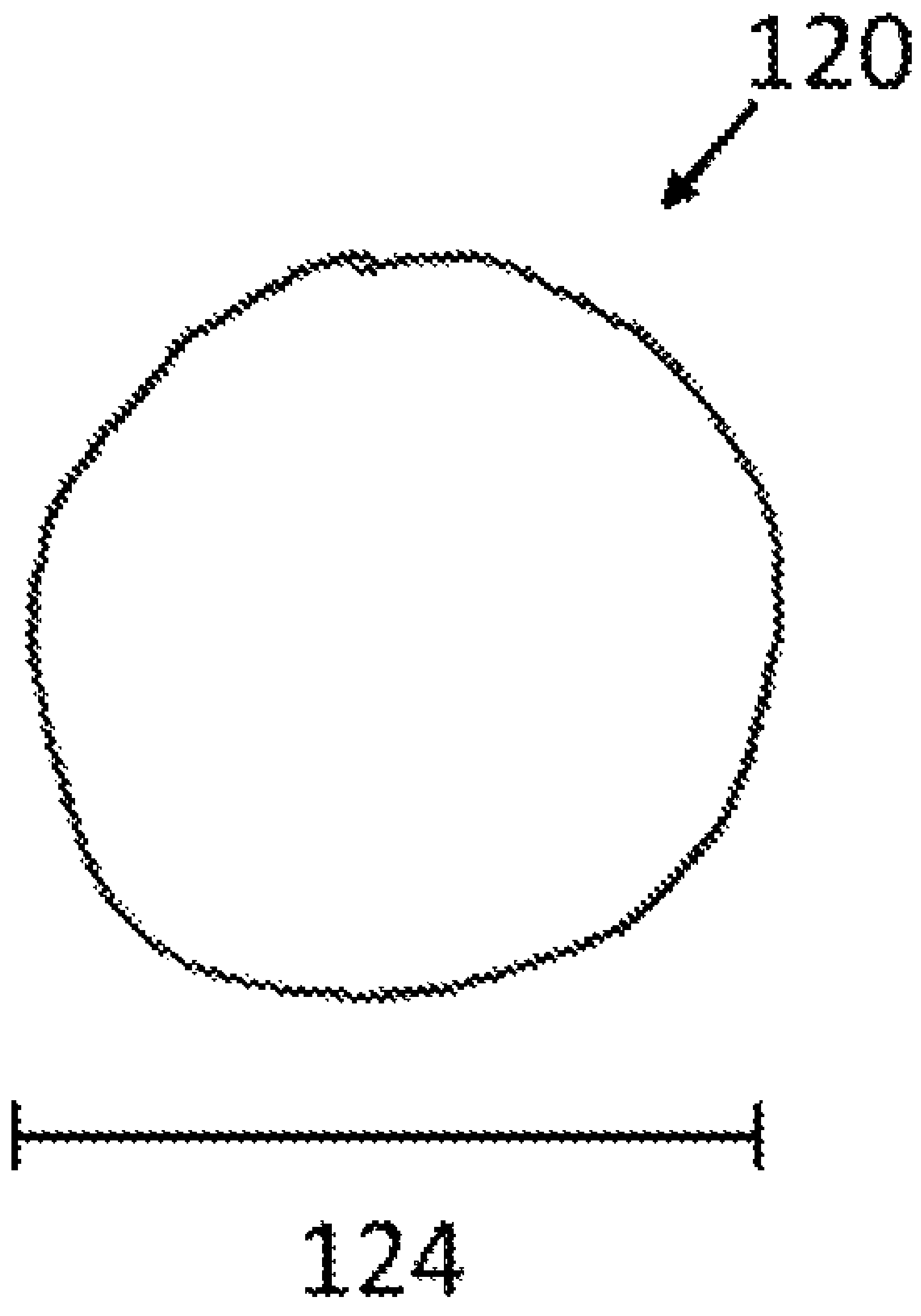

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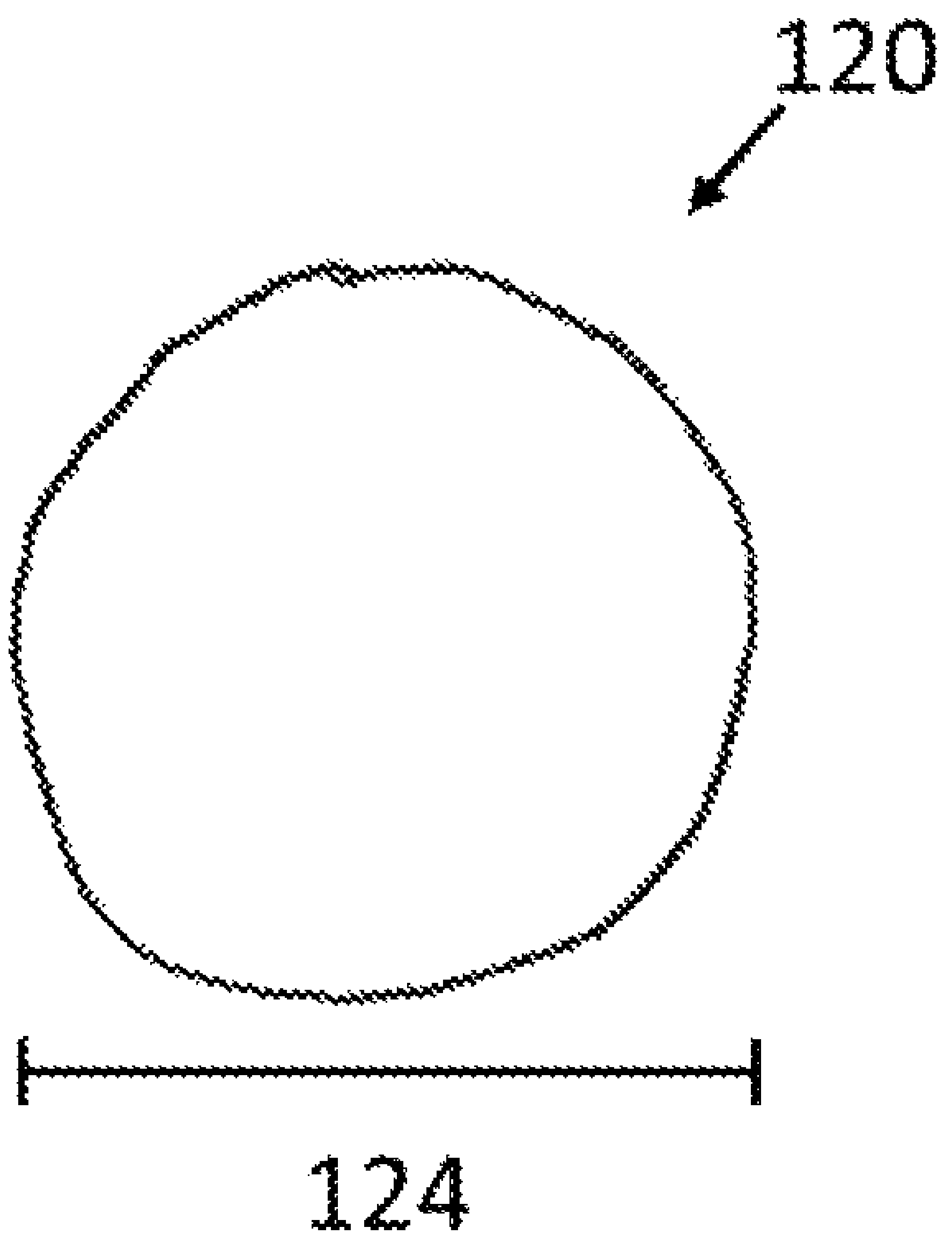

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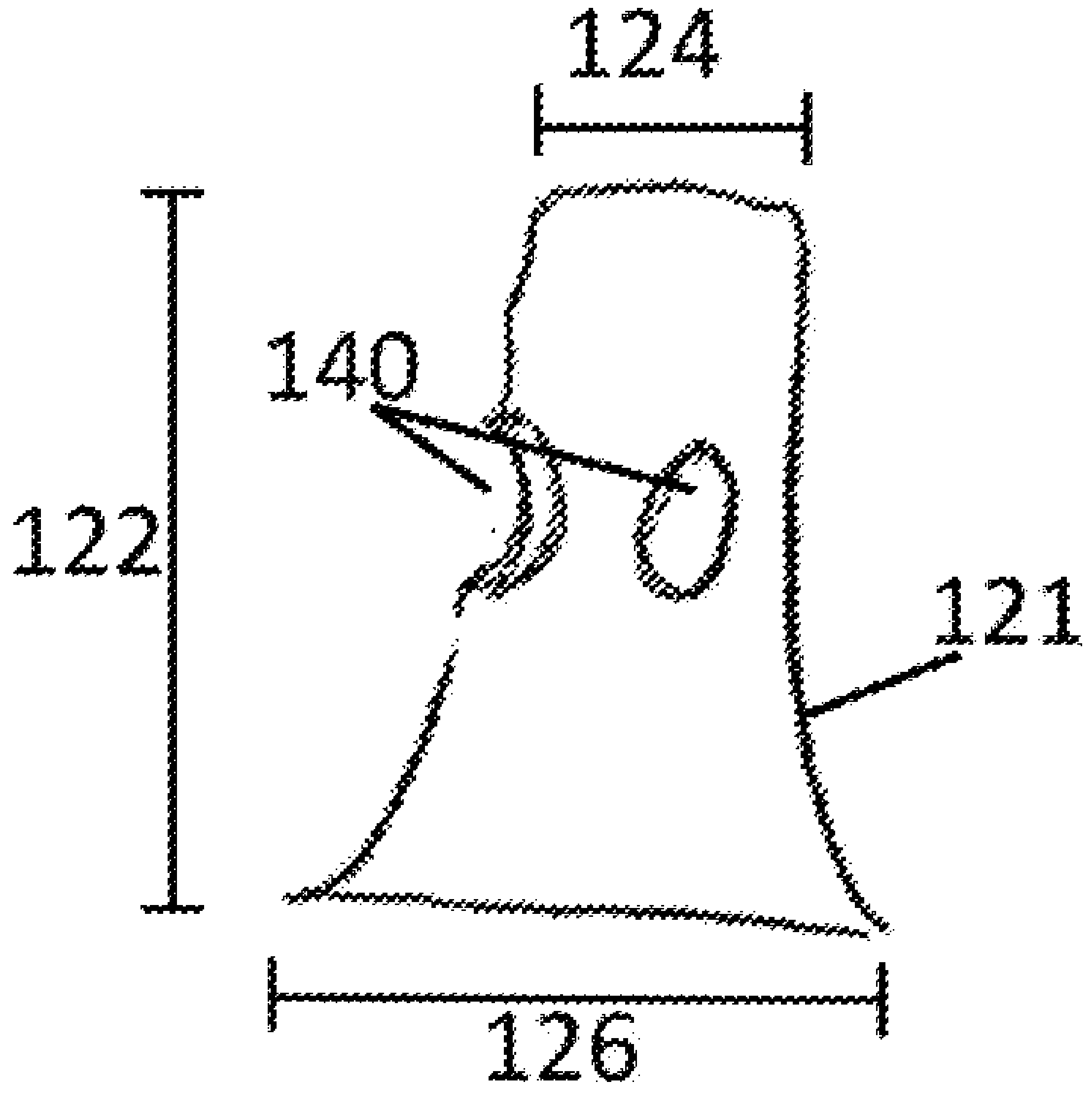

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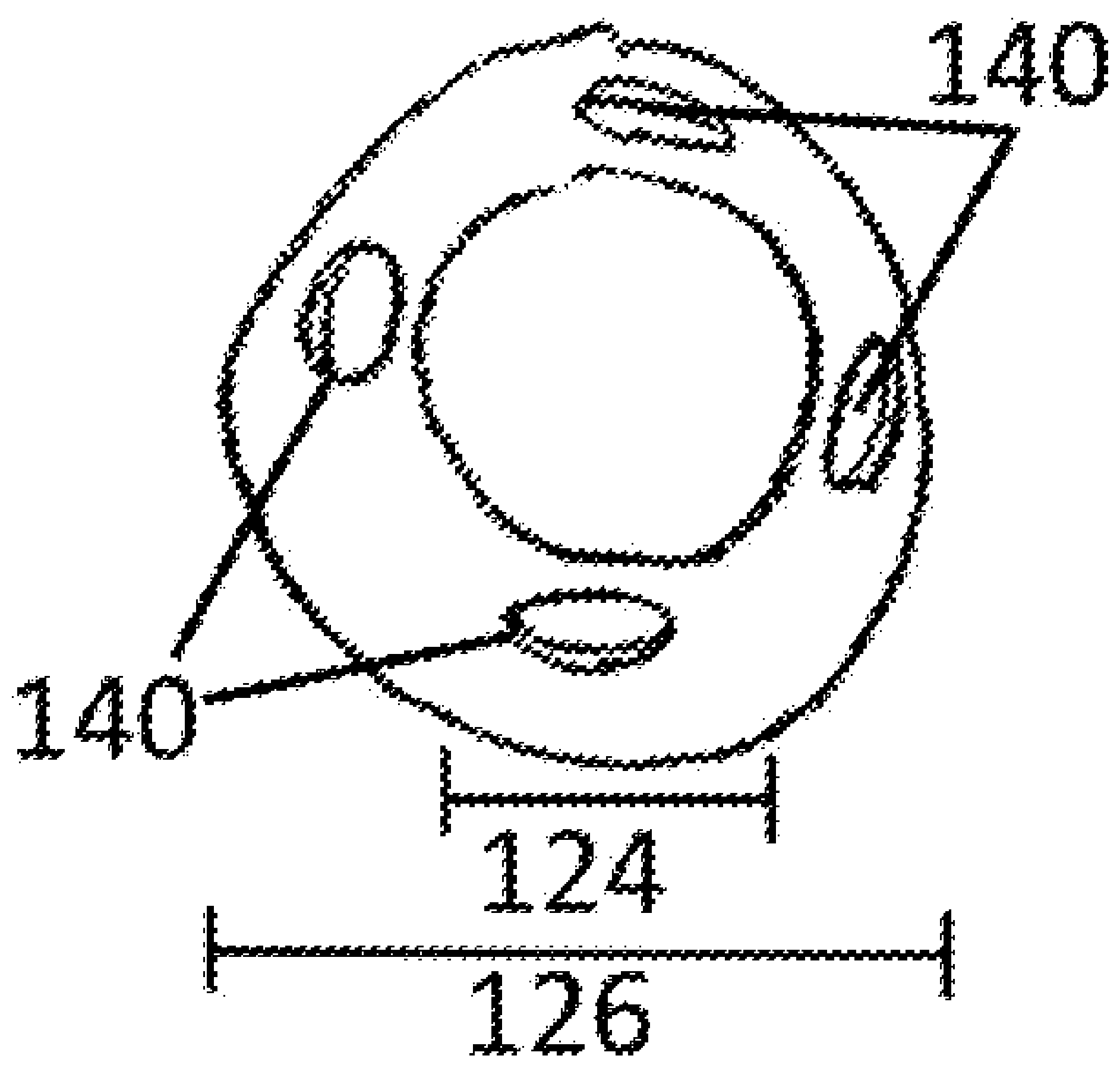


FIG. 8F

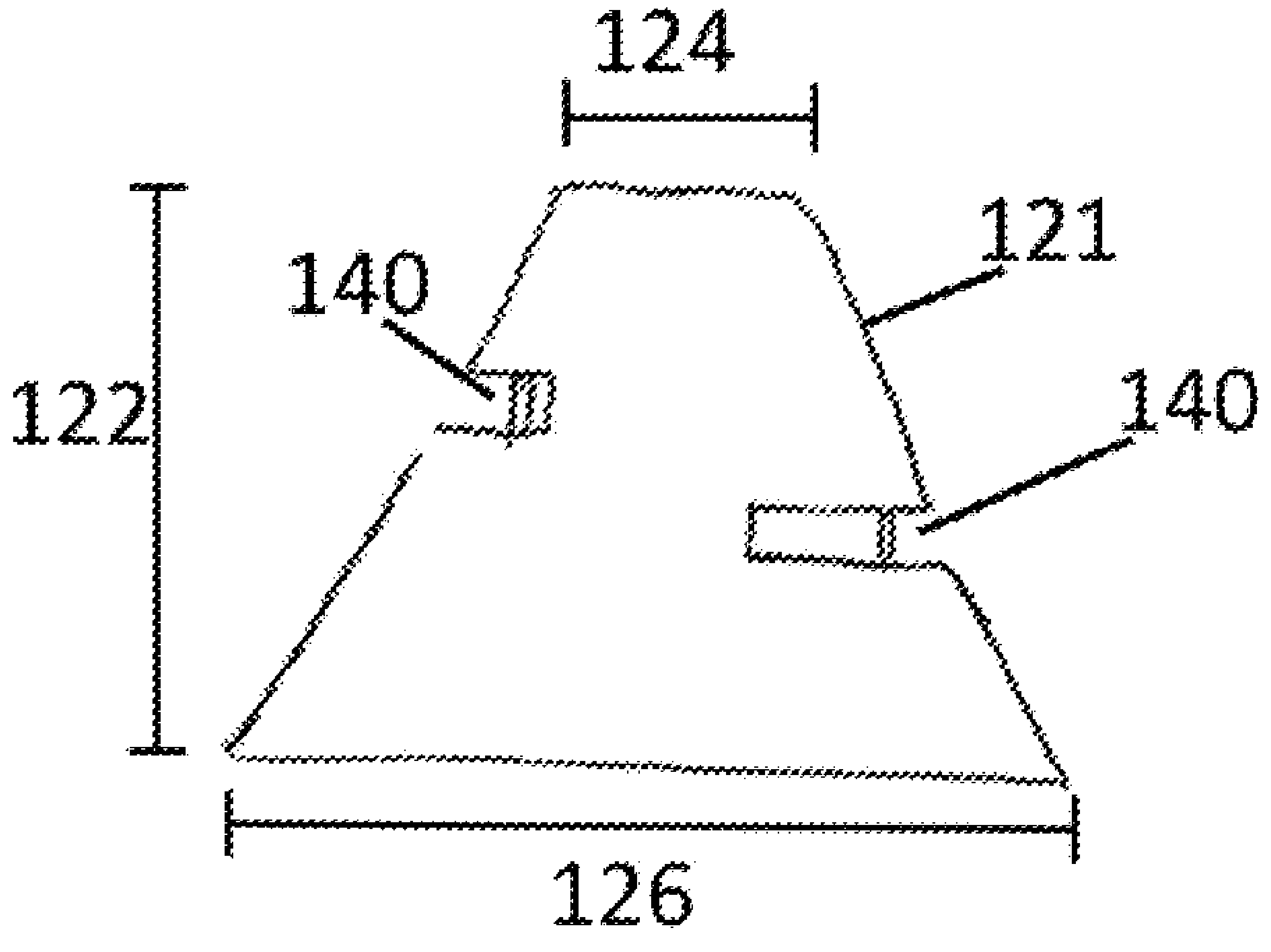


FIG. 8G

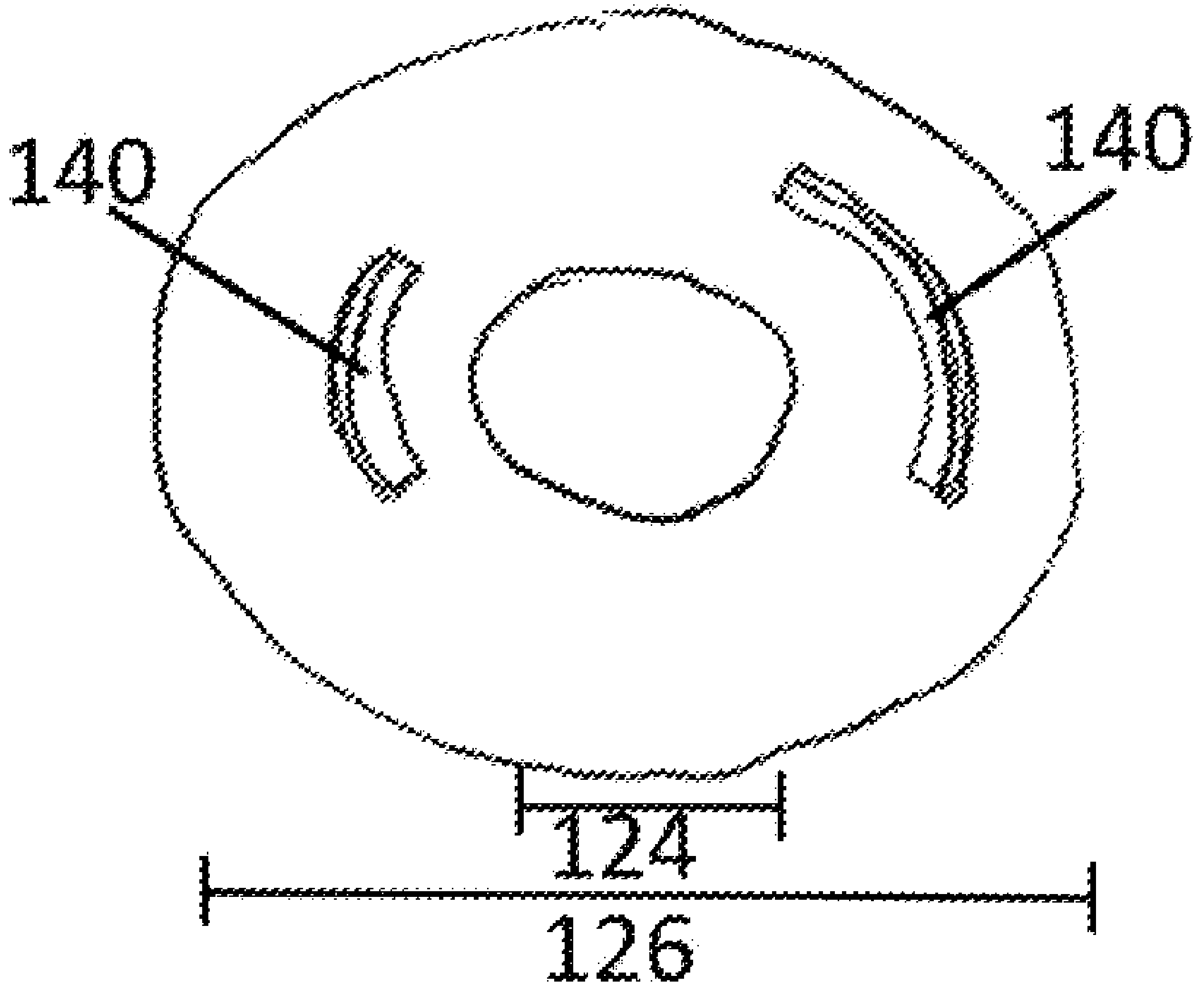


FIG. 8H

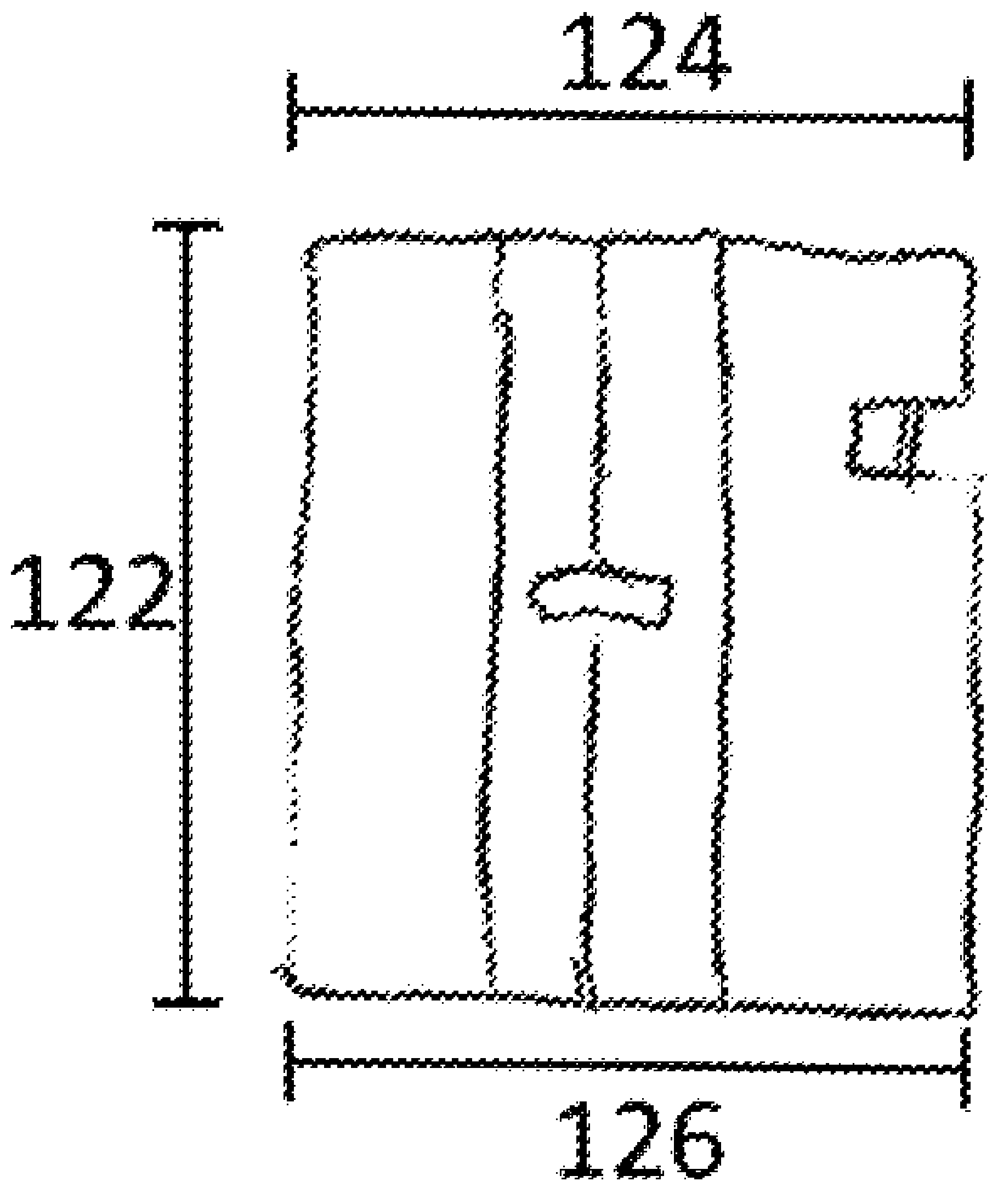
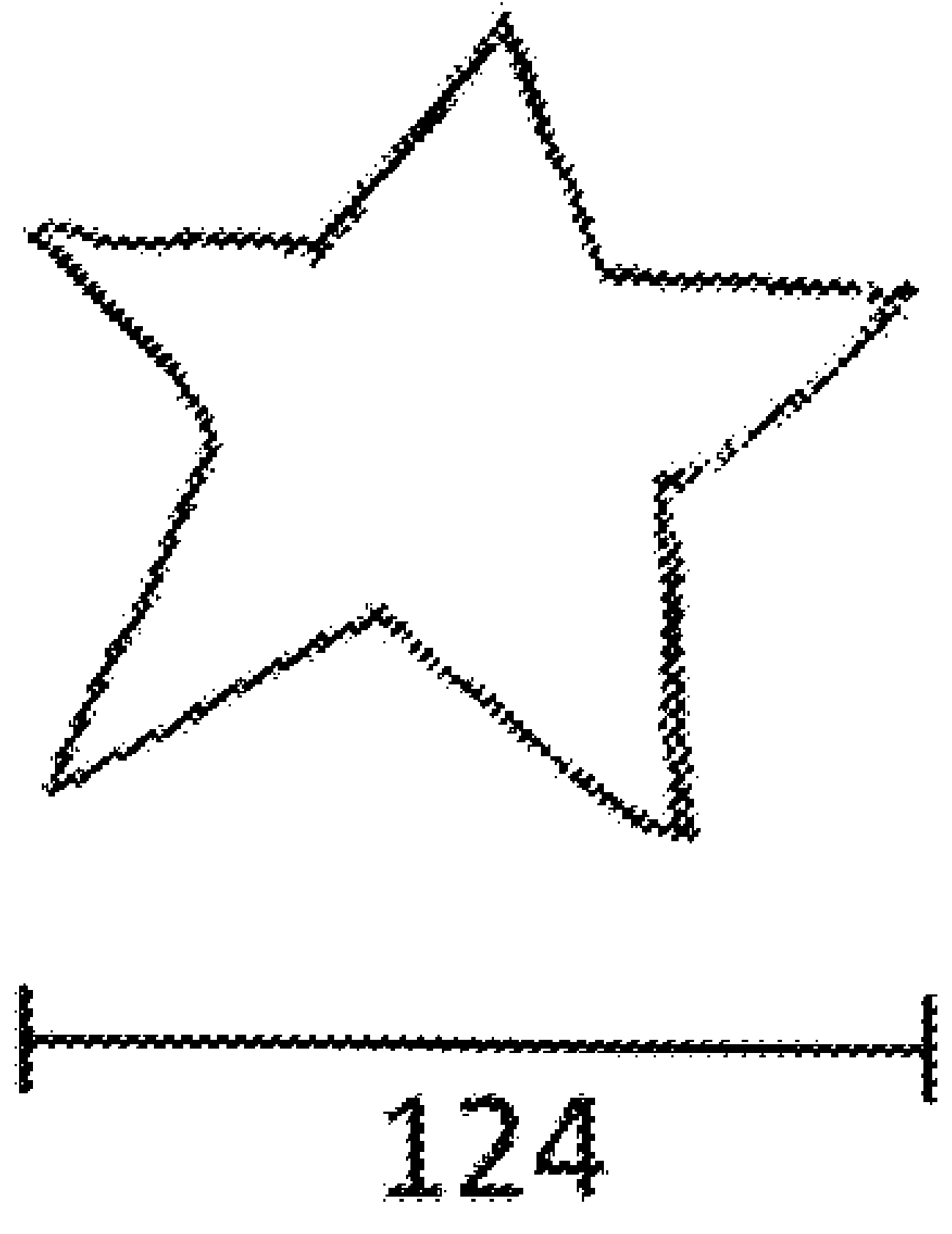


FIG. 8I



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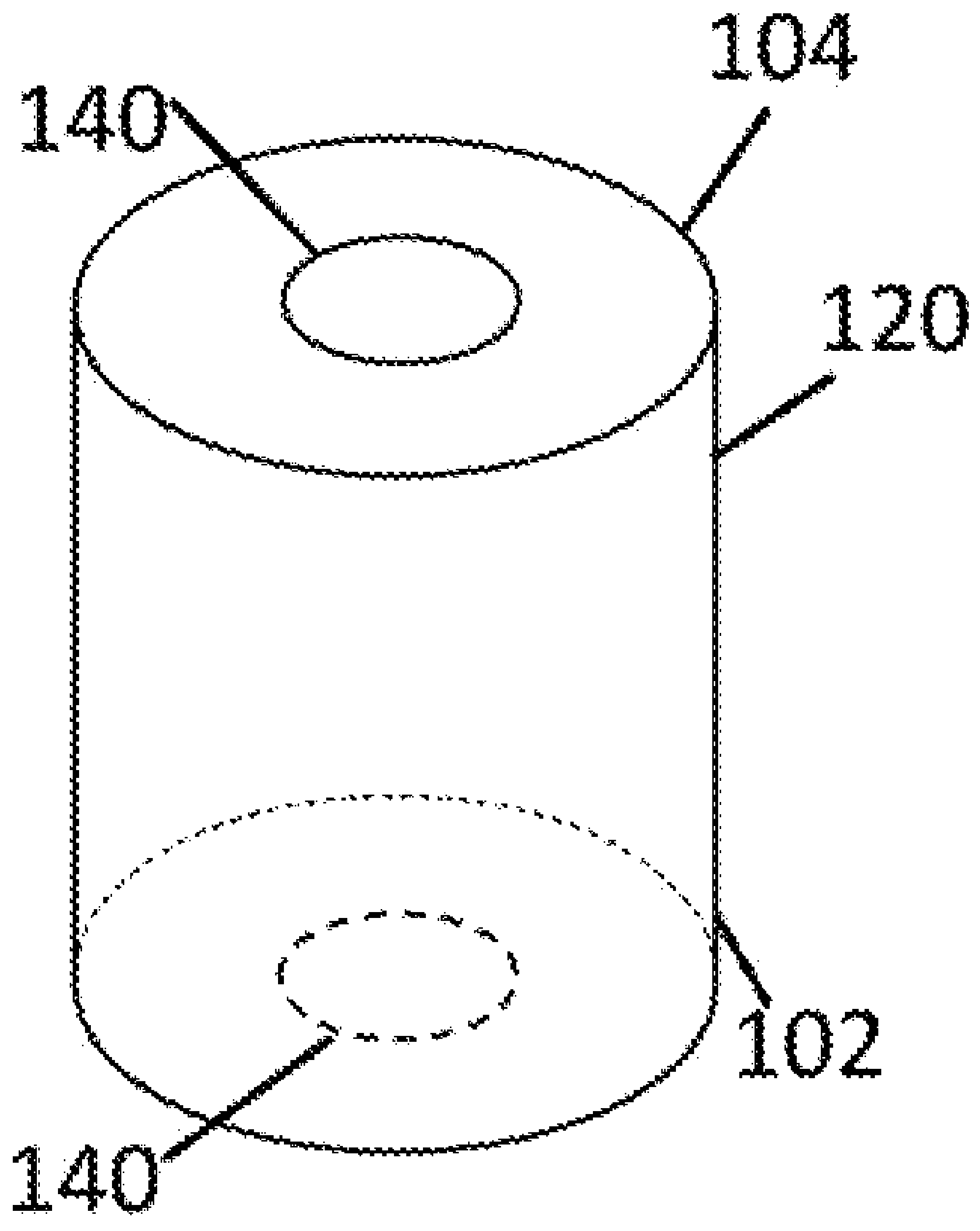
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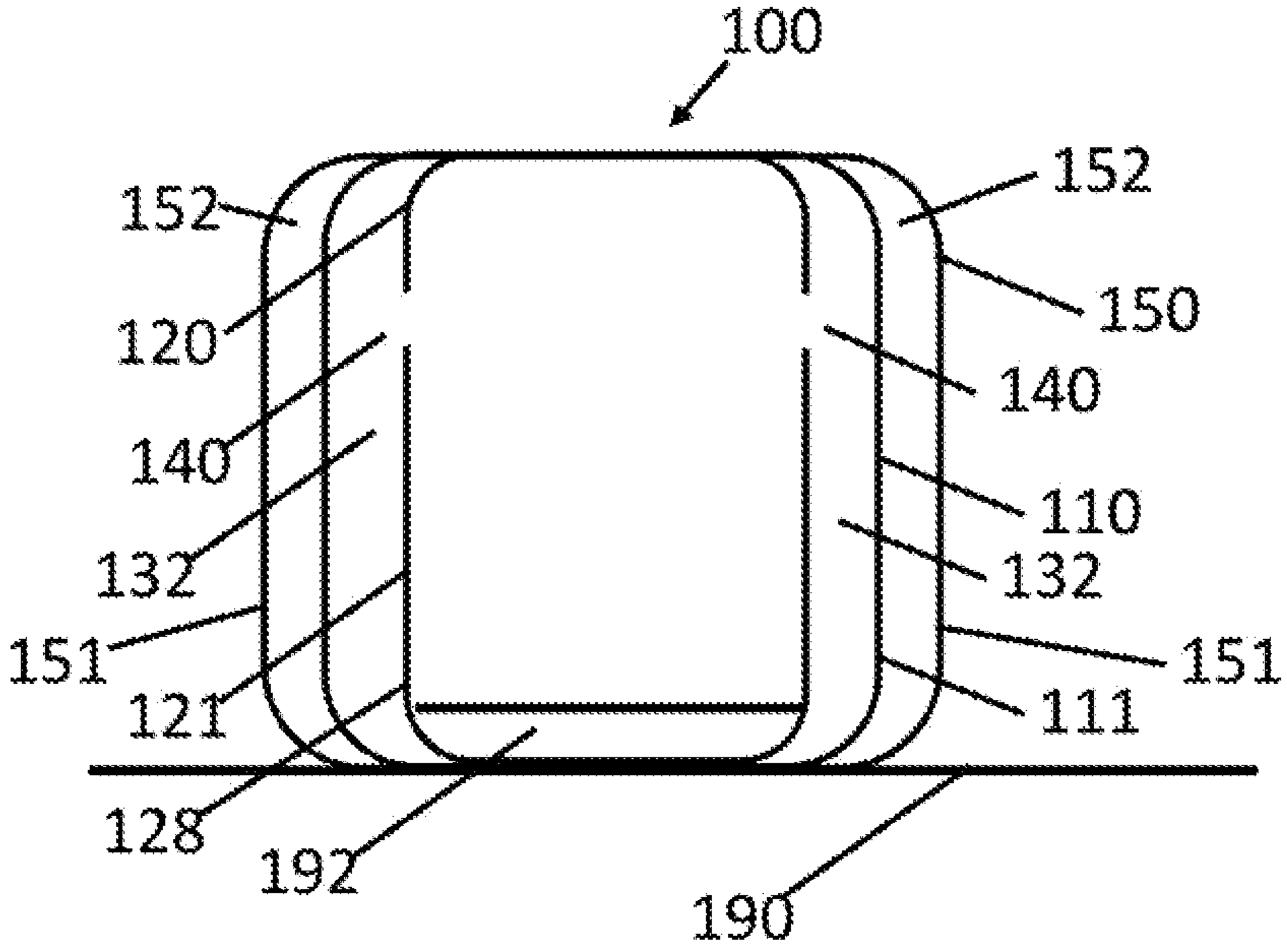
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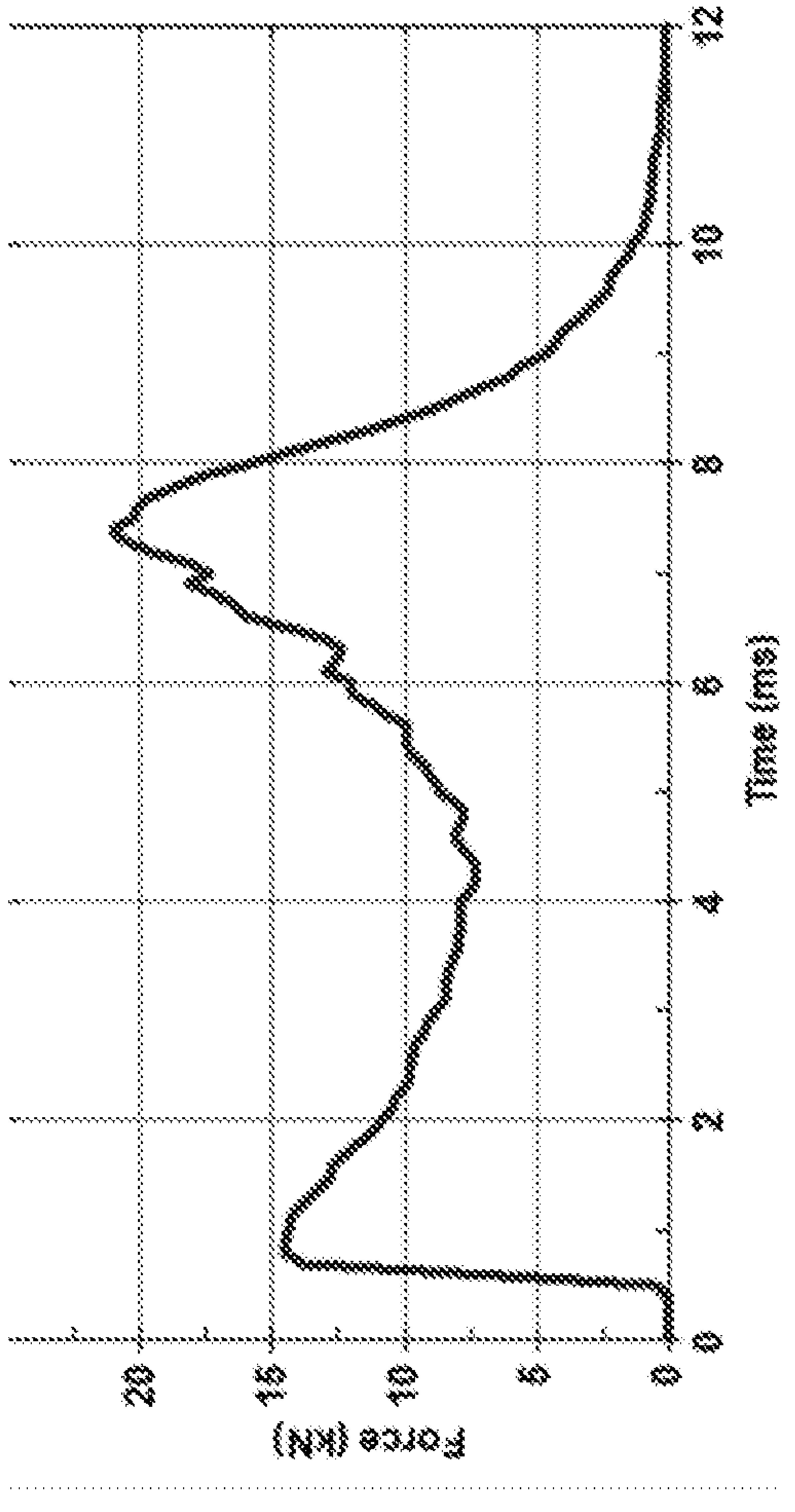
FIG. 9B



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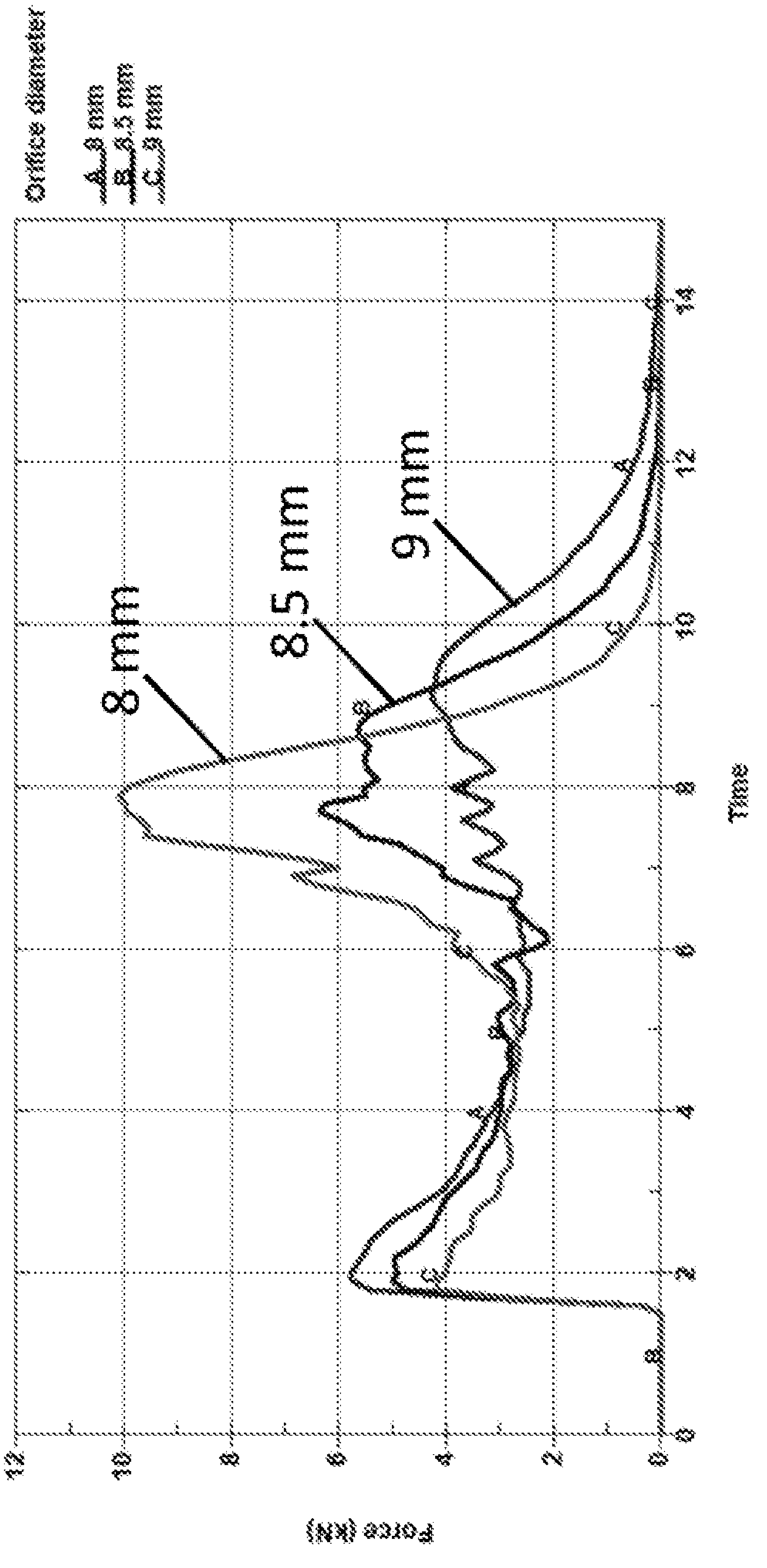

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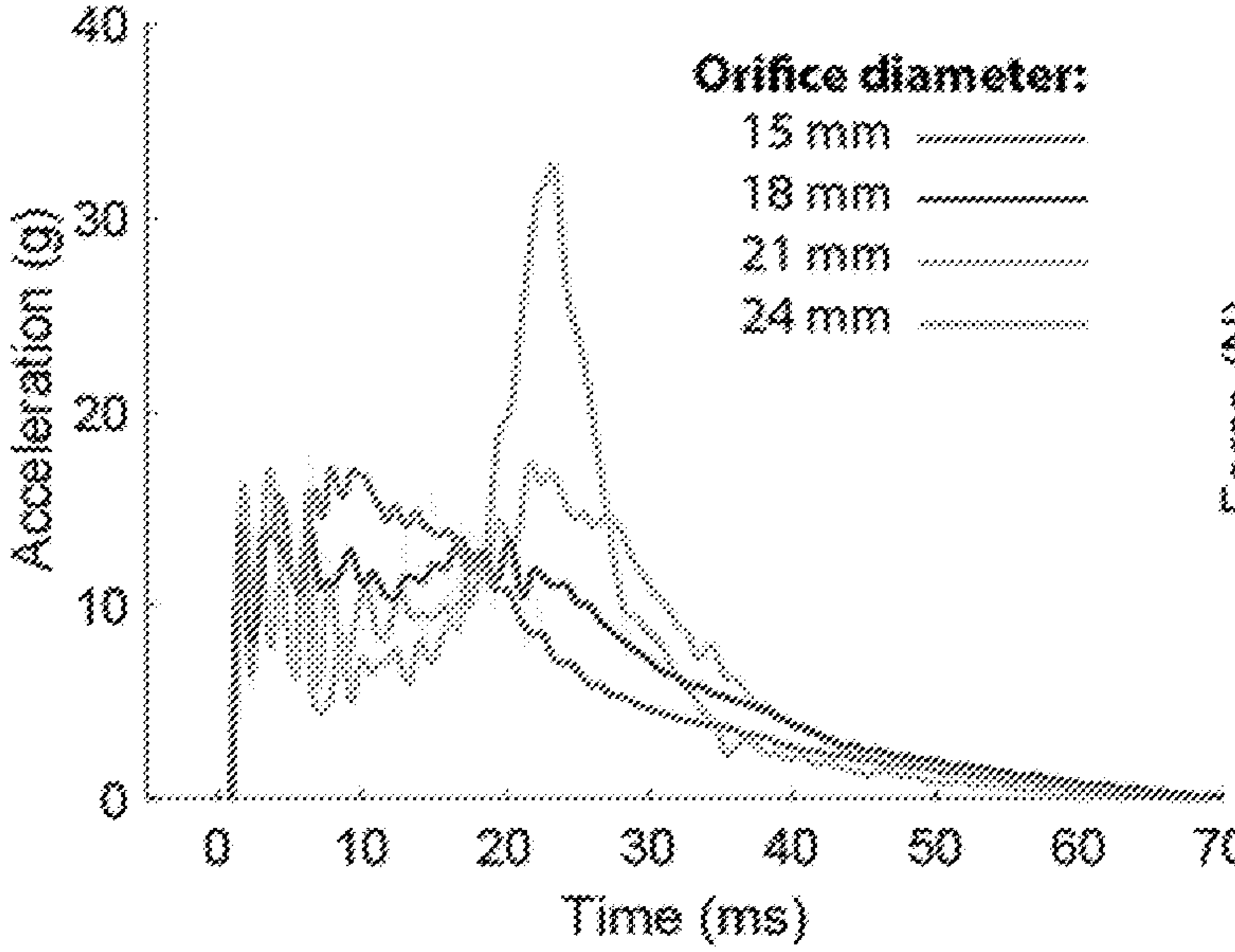

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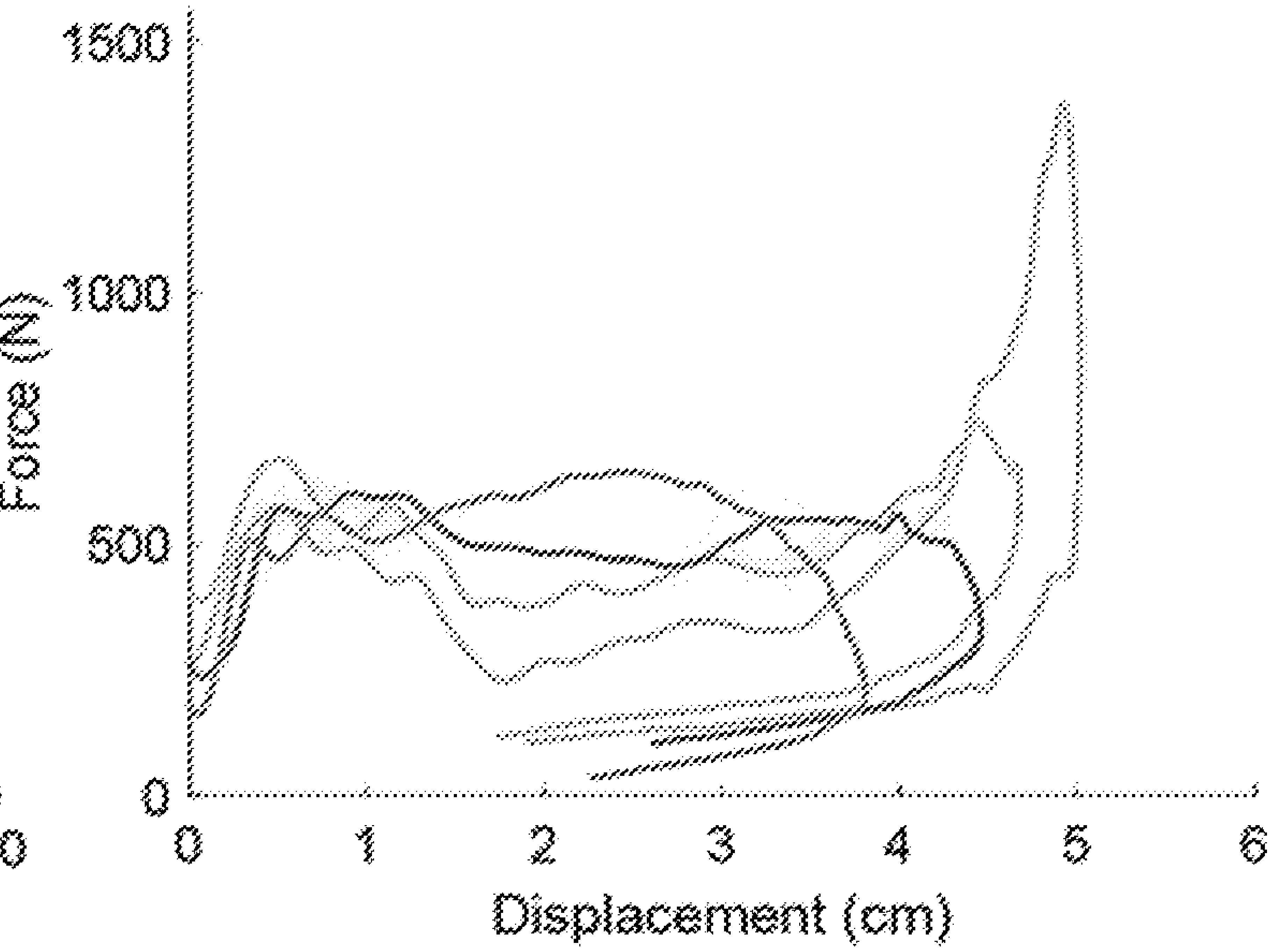

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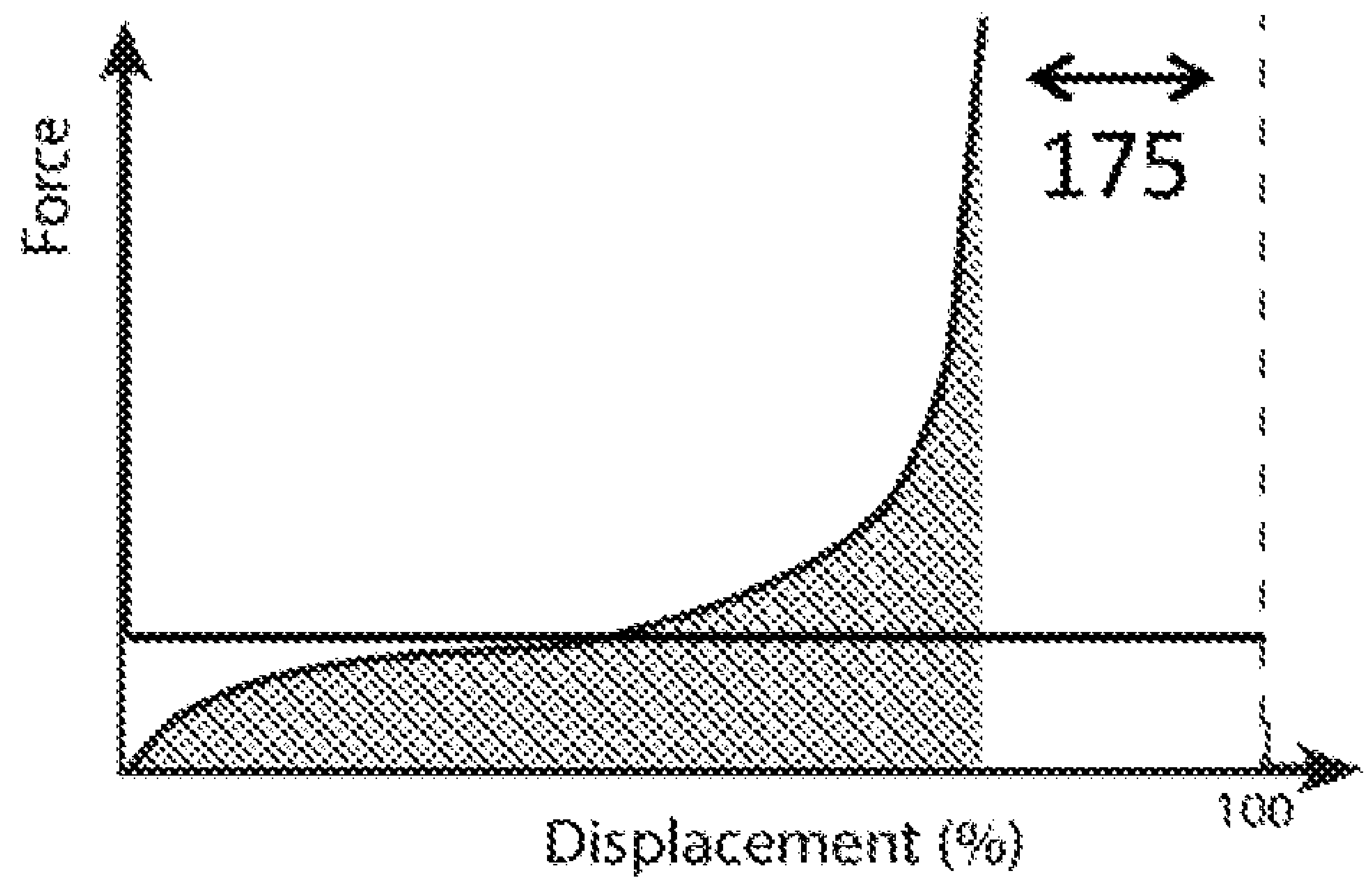

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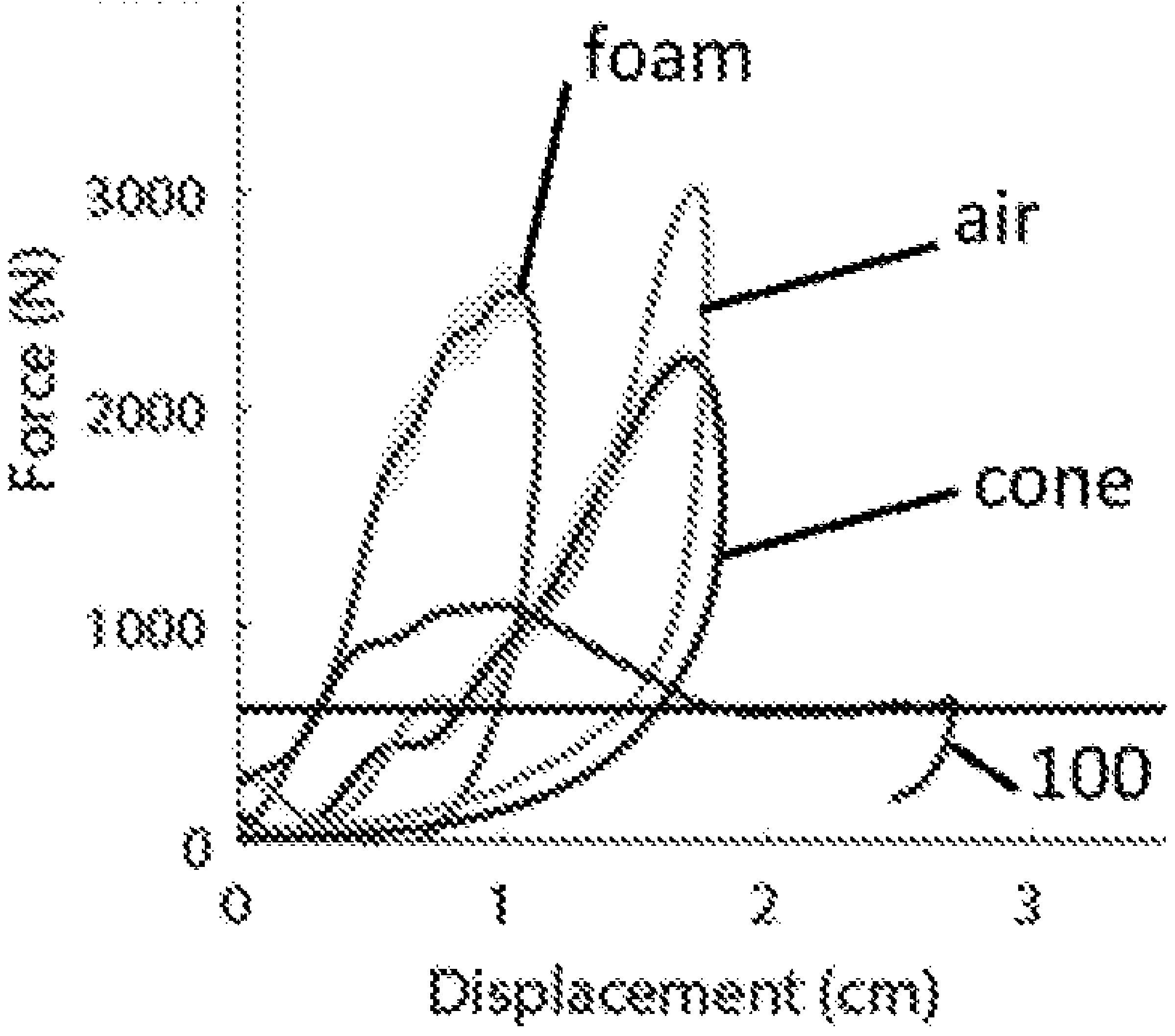

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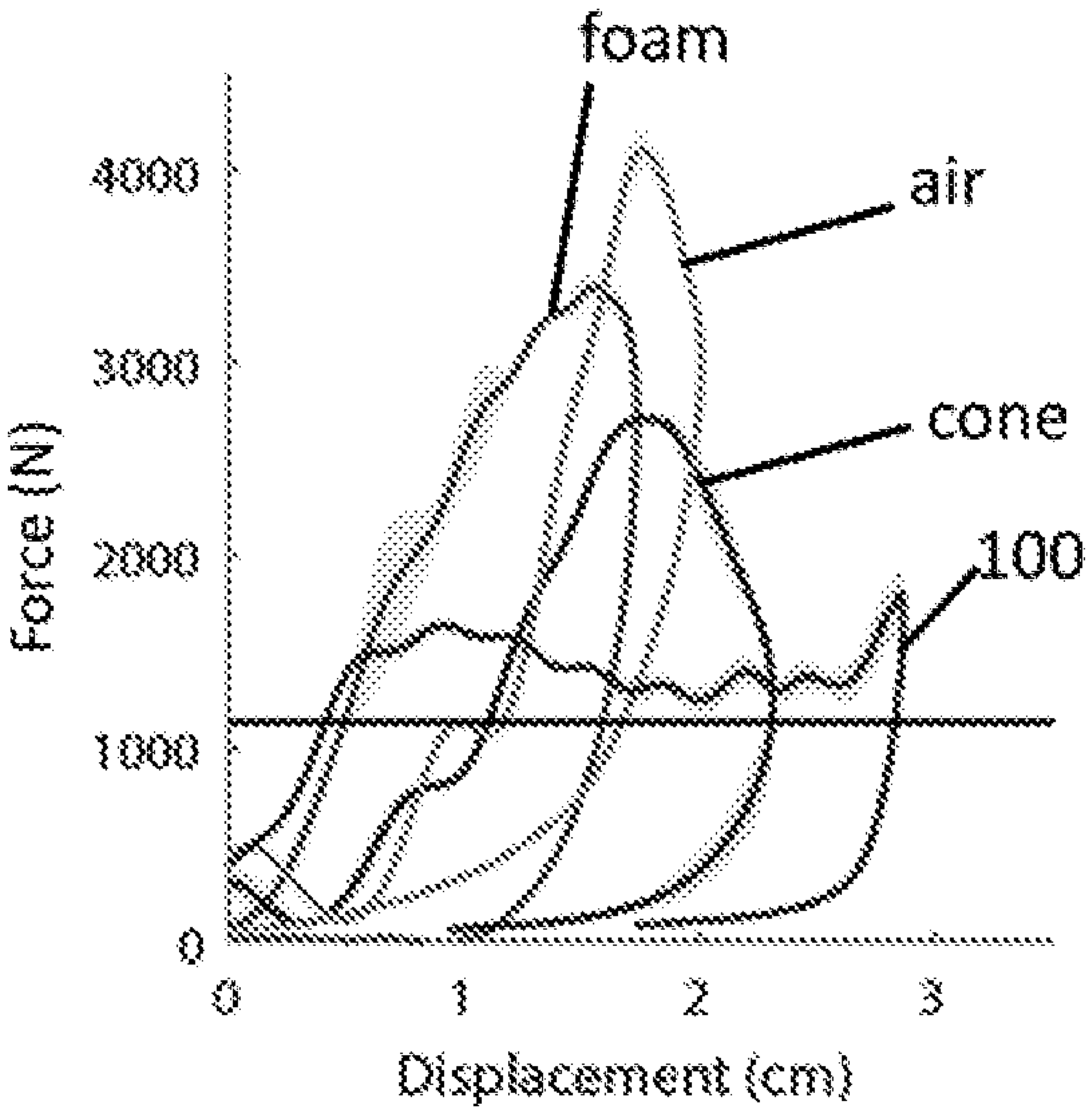

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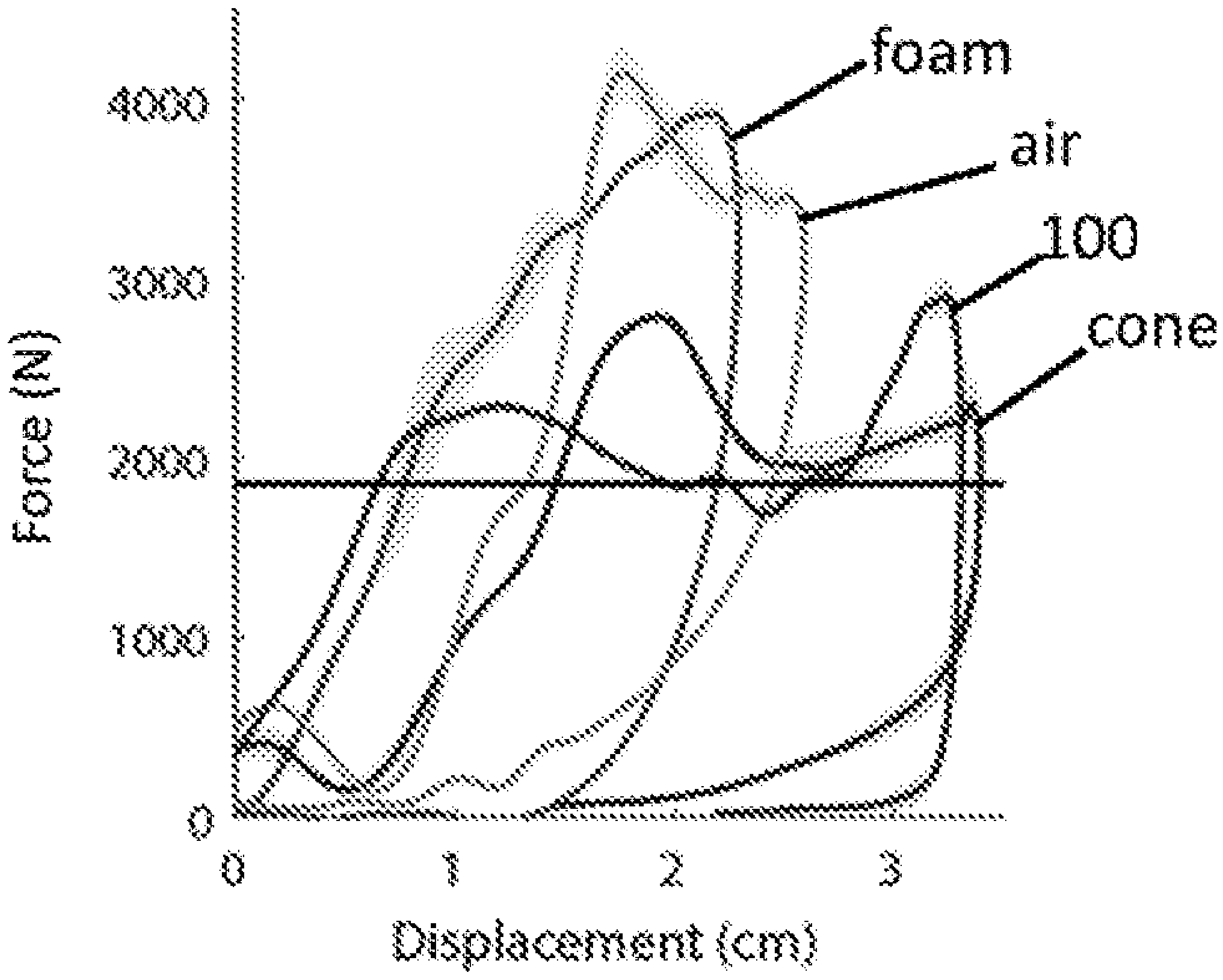

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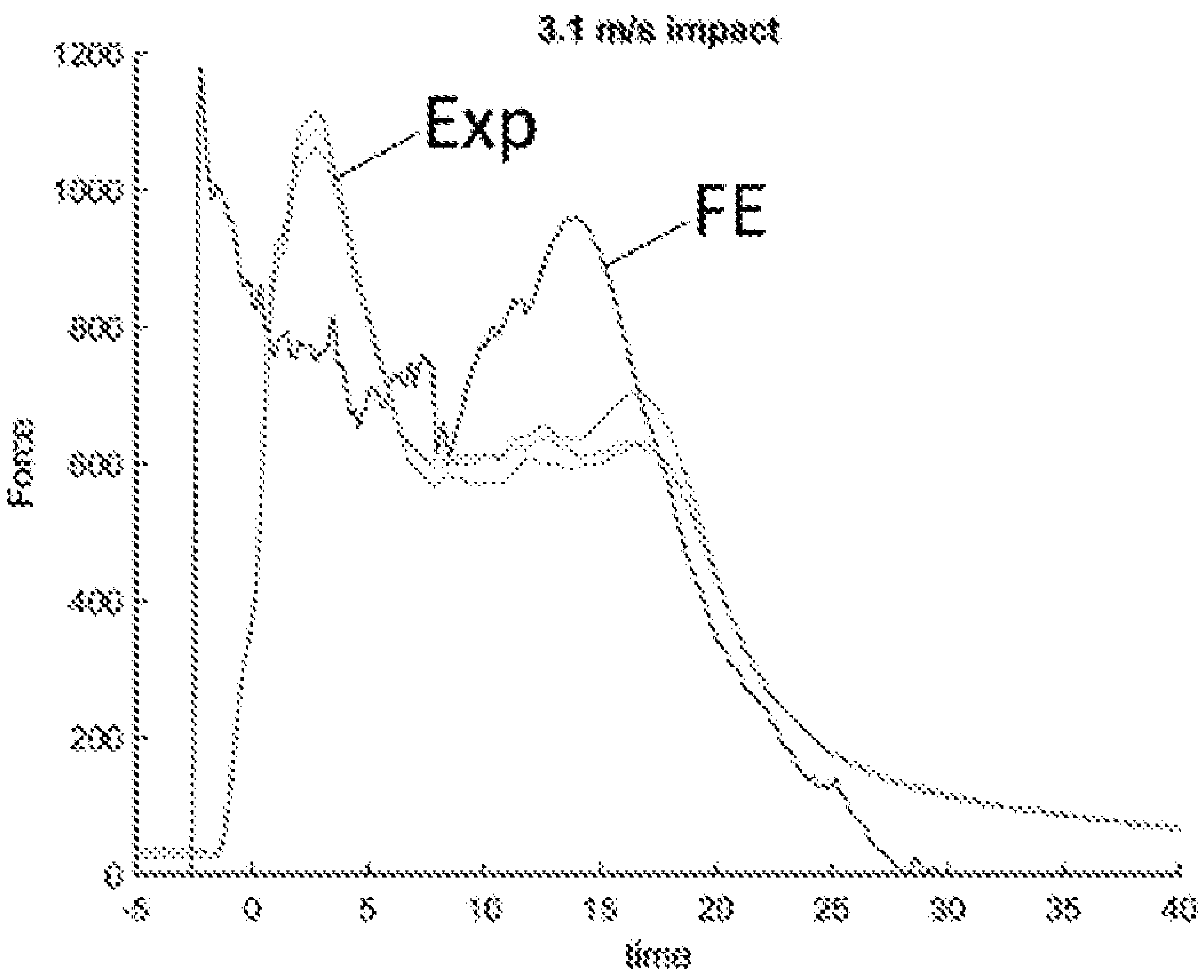

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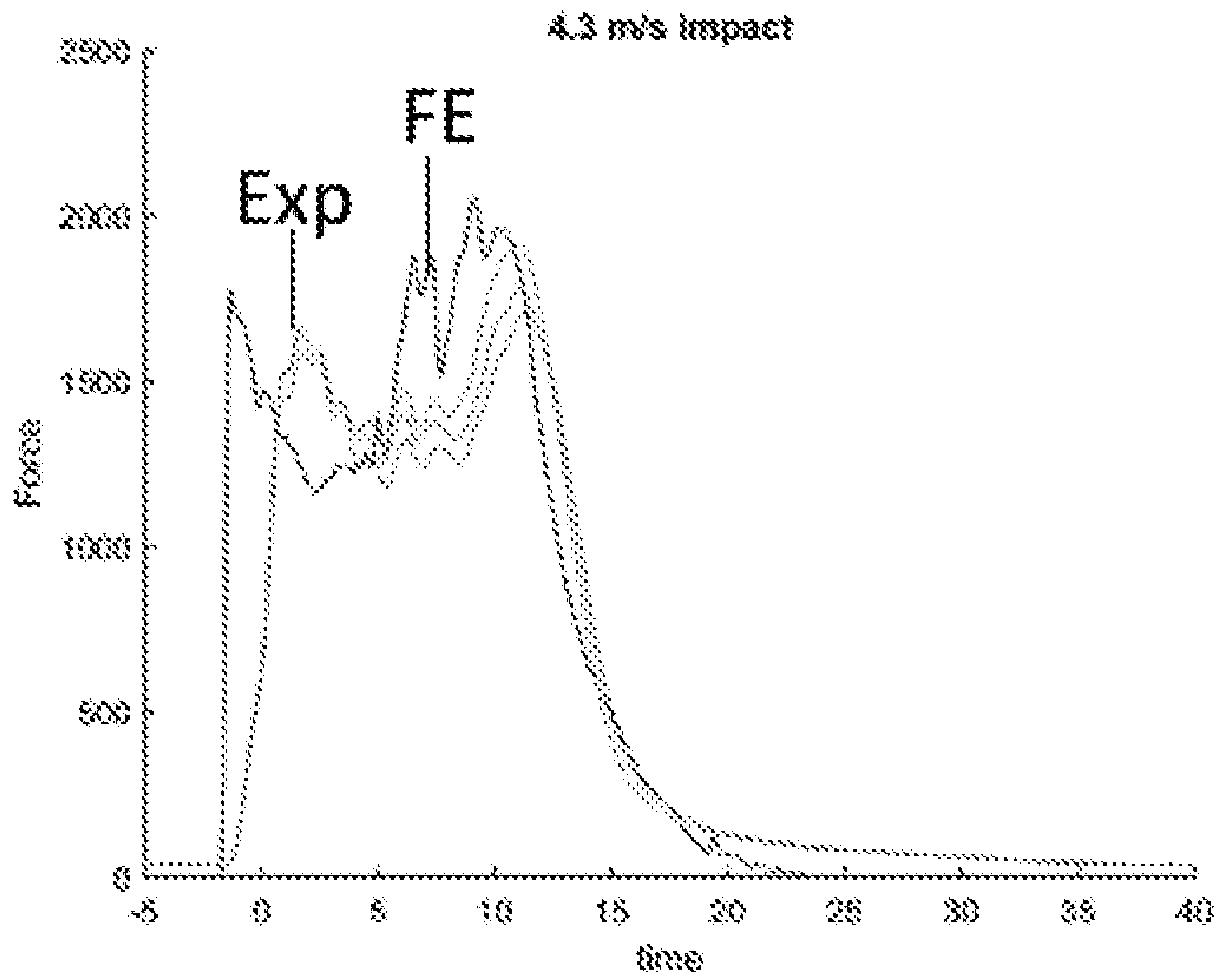


FIG. 13B

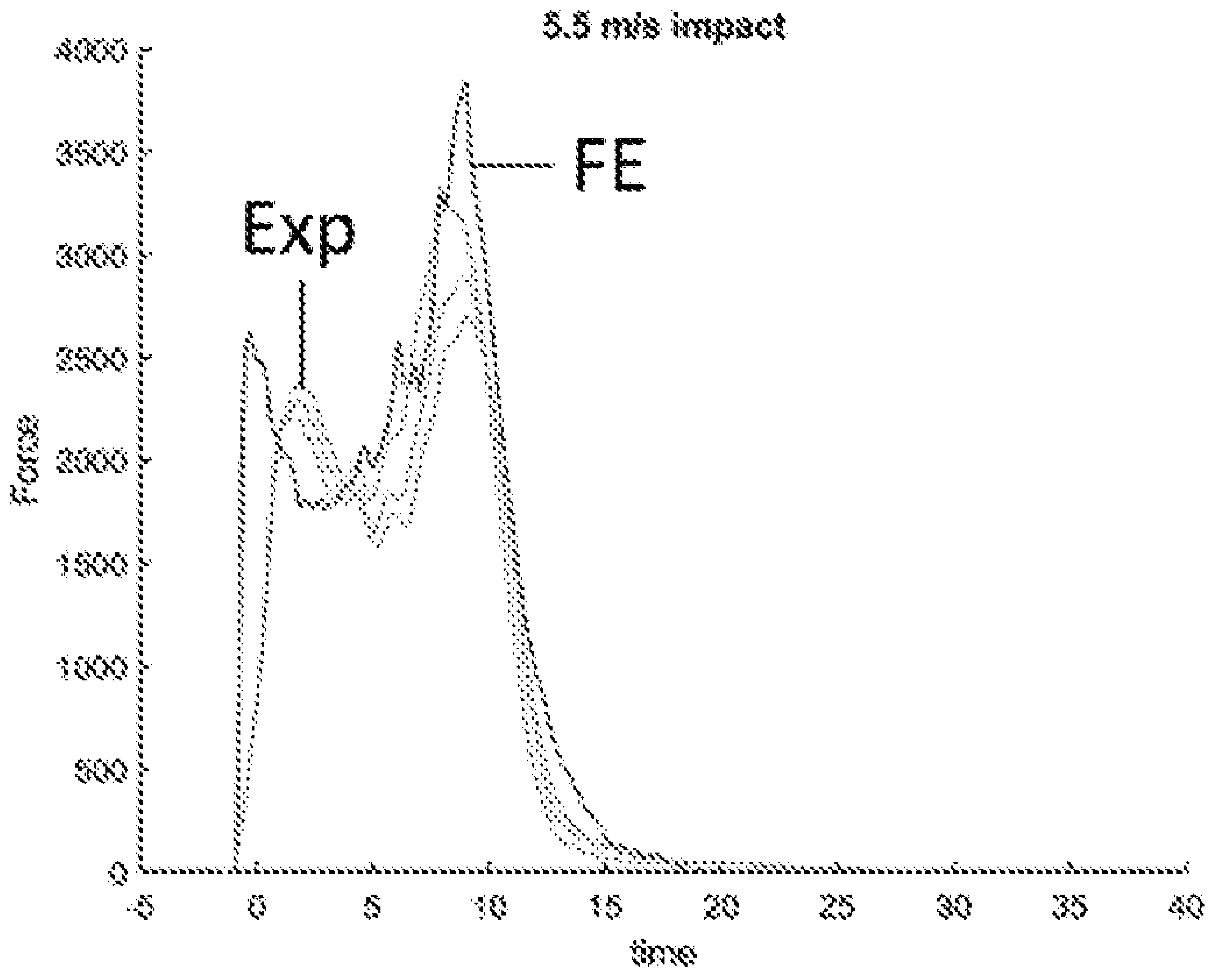


FIG. 13C

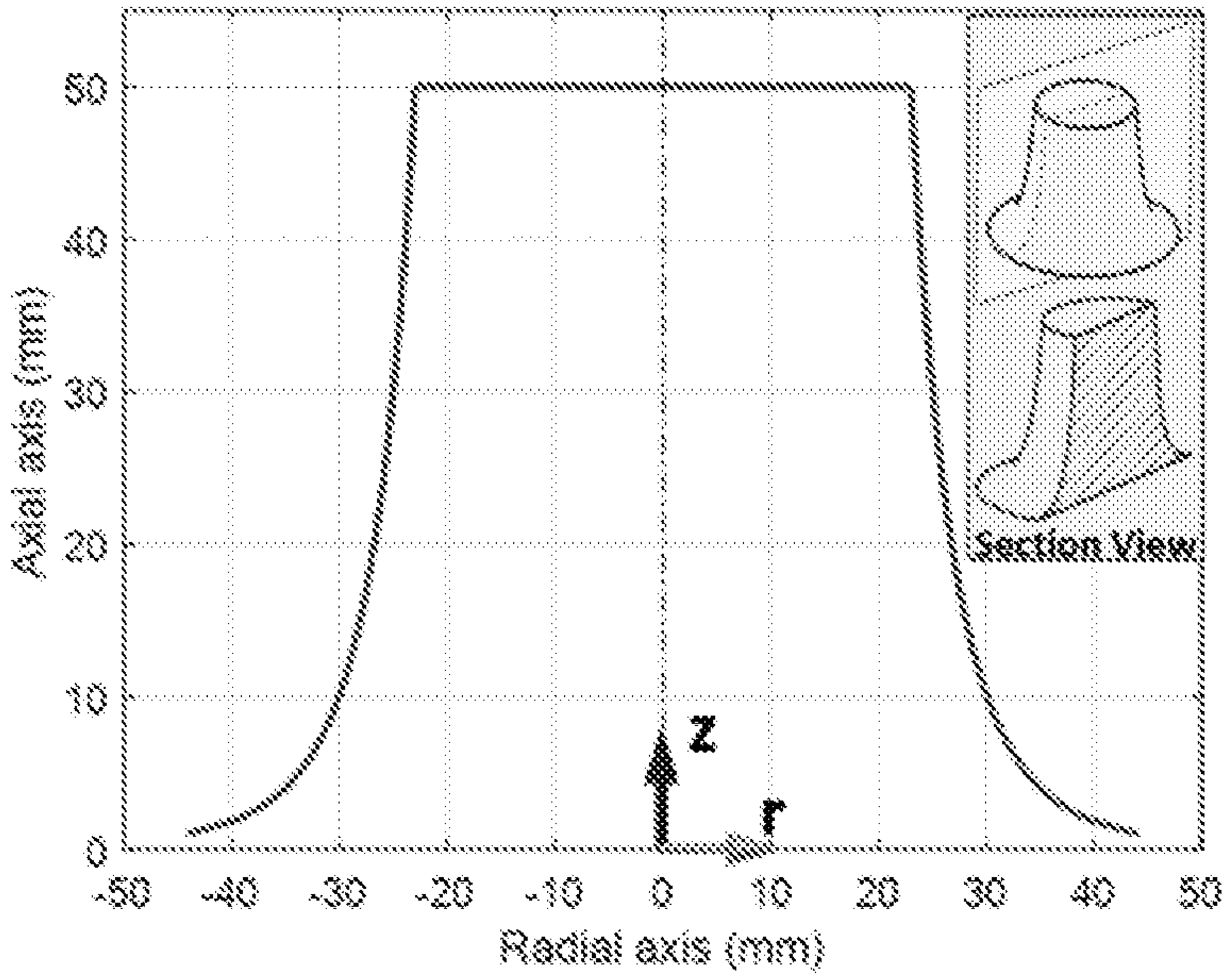


FIG. 14A

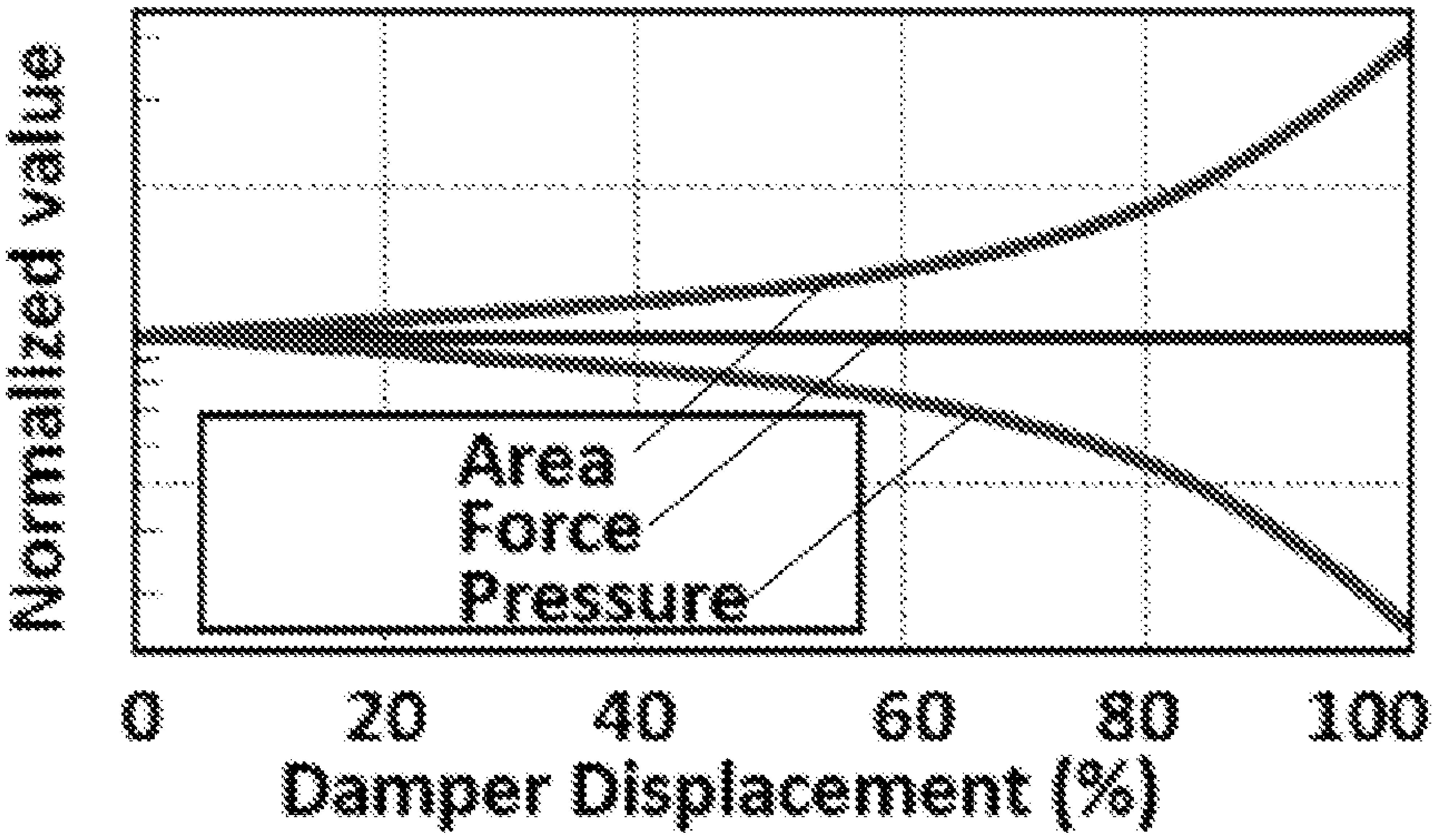
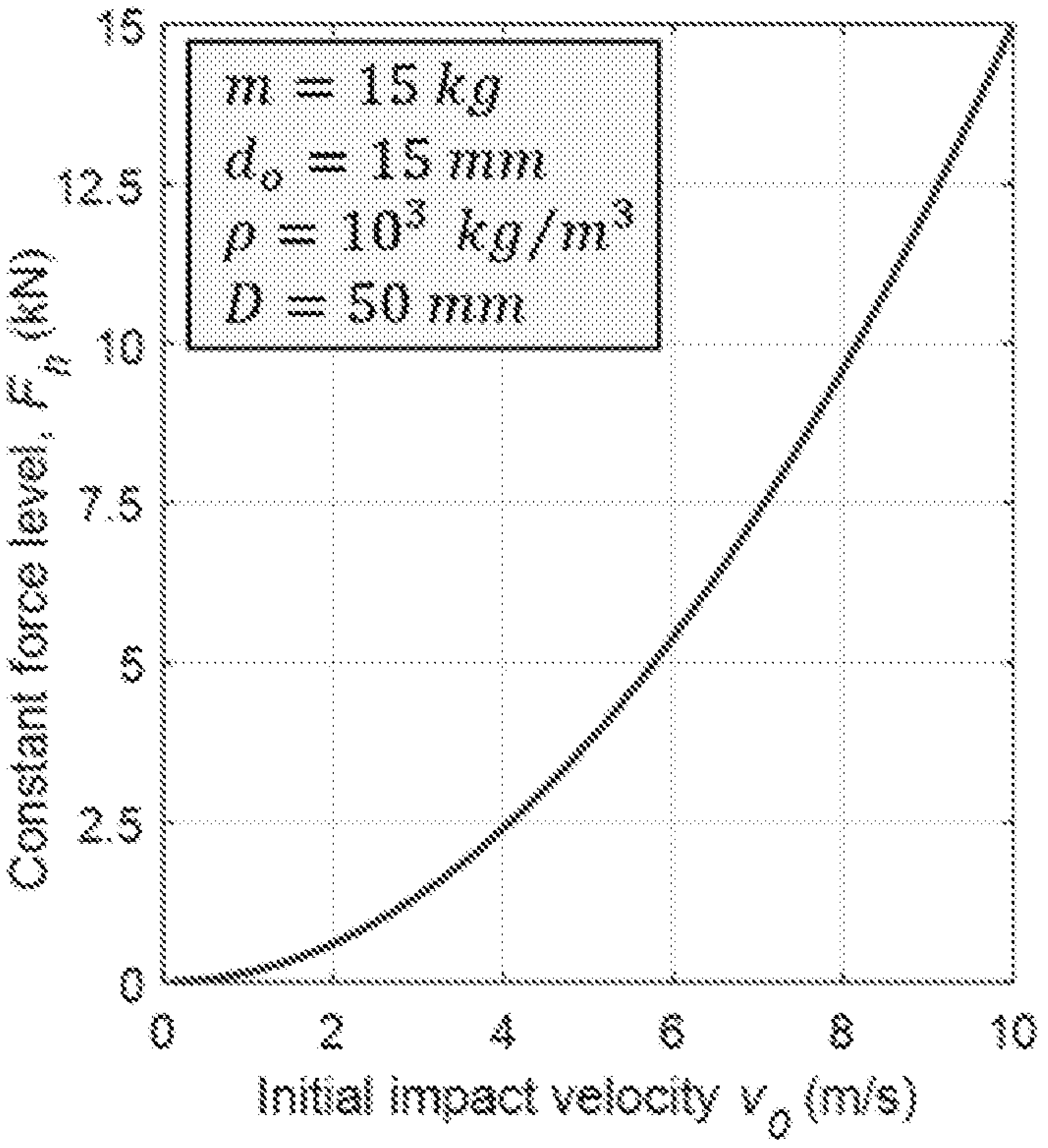


FIG. 14B

FIG. 14C



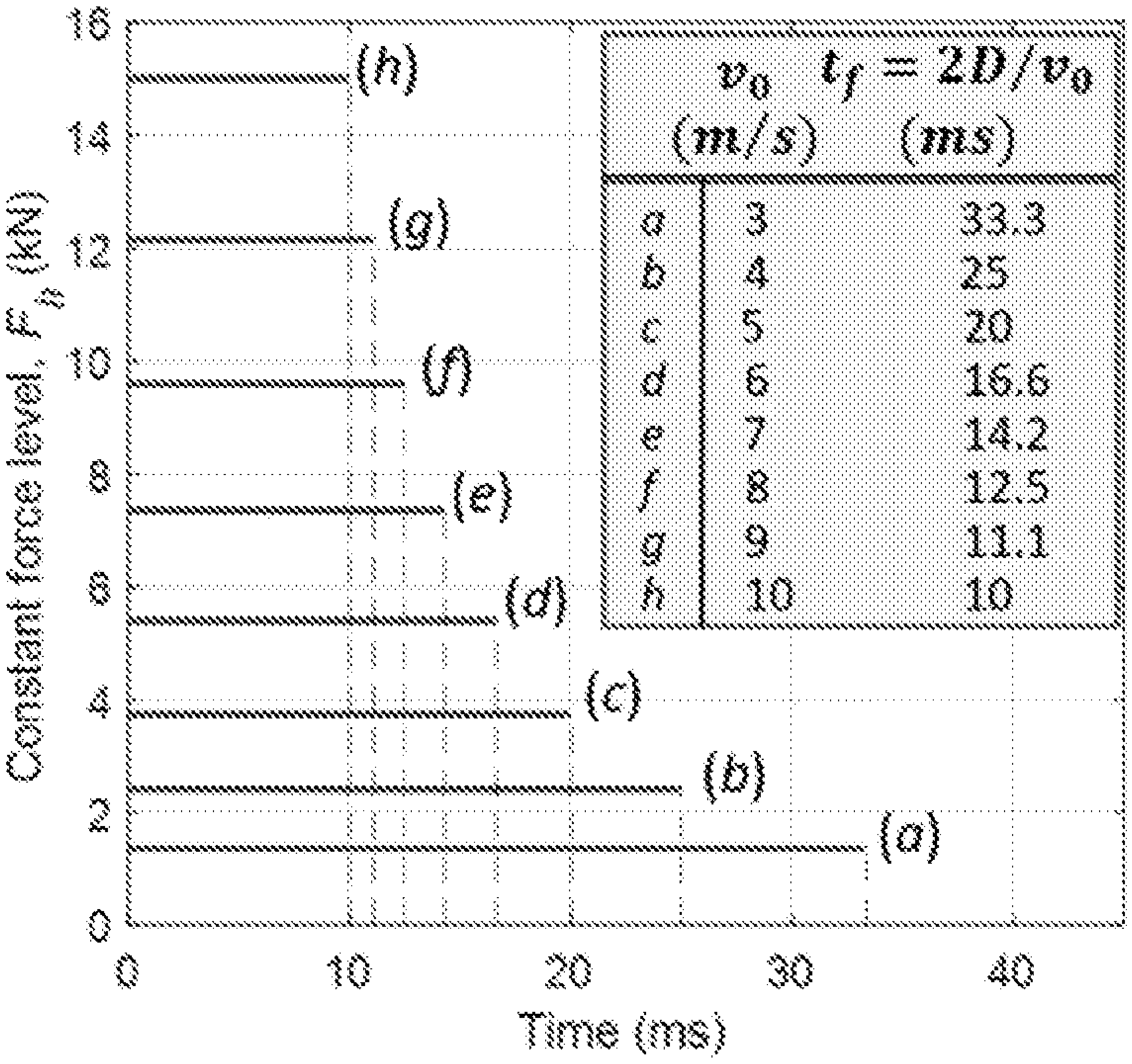


FIG. 14D

A. Fluid-filled shock absorber elements

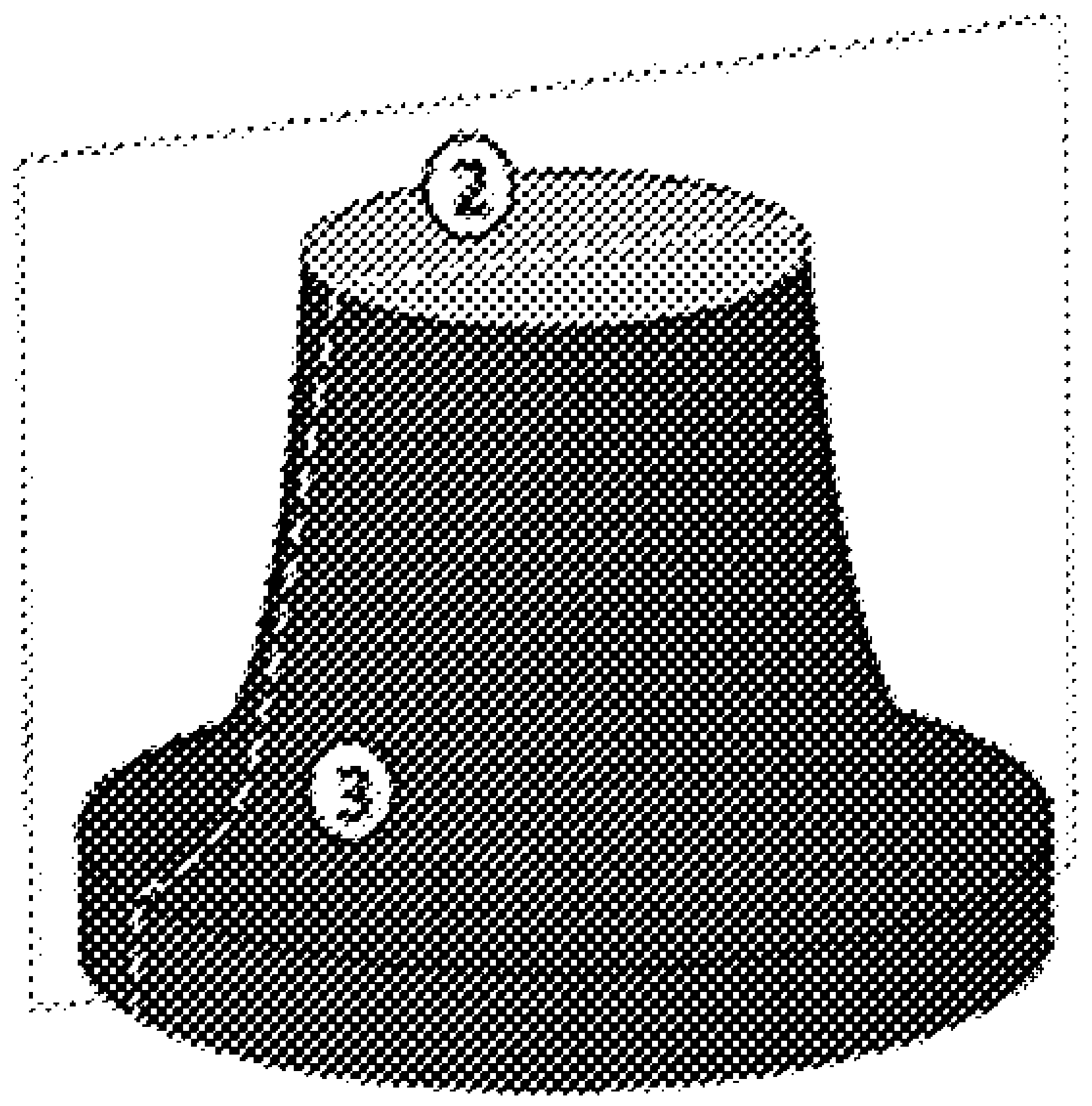


FIG. 15A

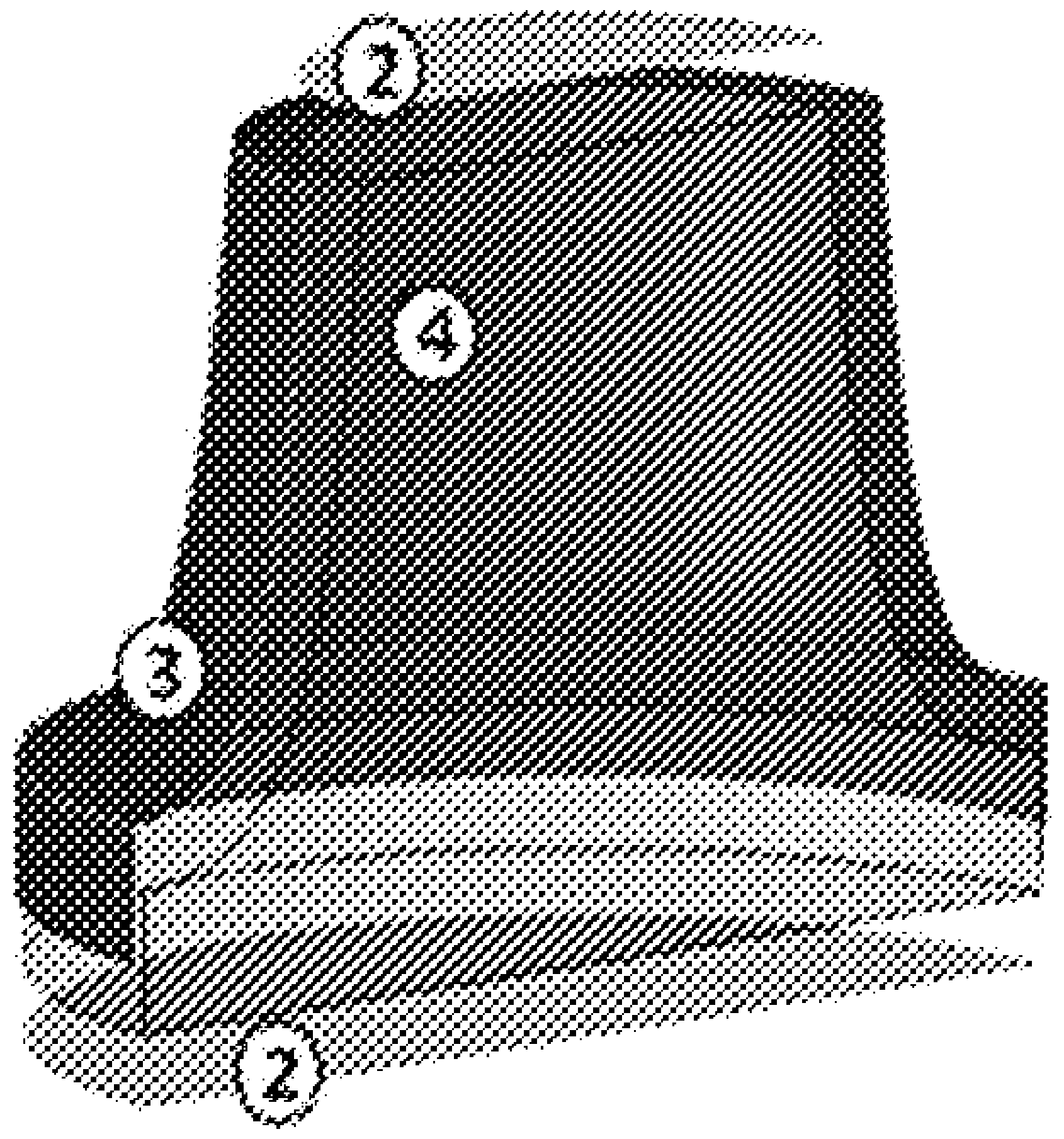


FIG. 15B

1 – Impacting mass
2 – Solid endcaps
3 – High-strength Fabric
4 – Incompressible fluid
(Control Volume with orifice)
5 – Solid base

B. FE model of variable area fluid damper

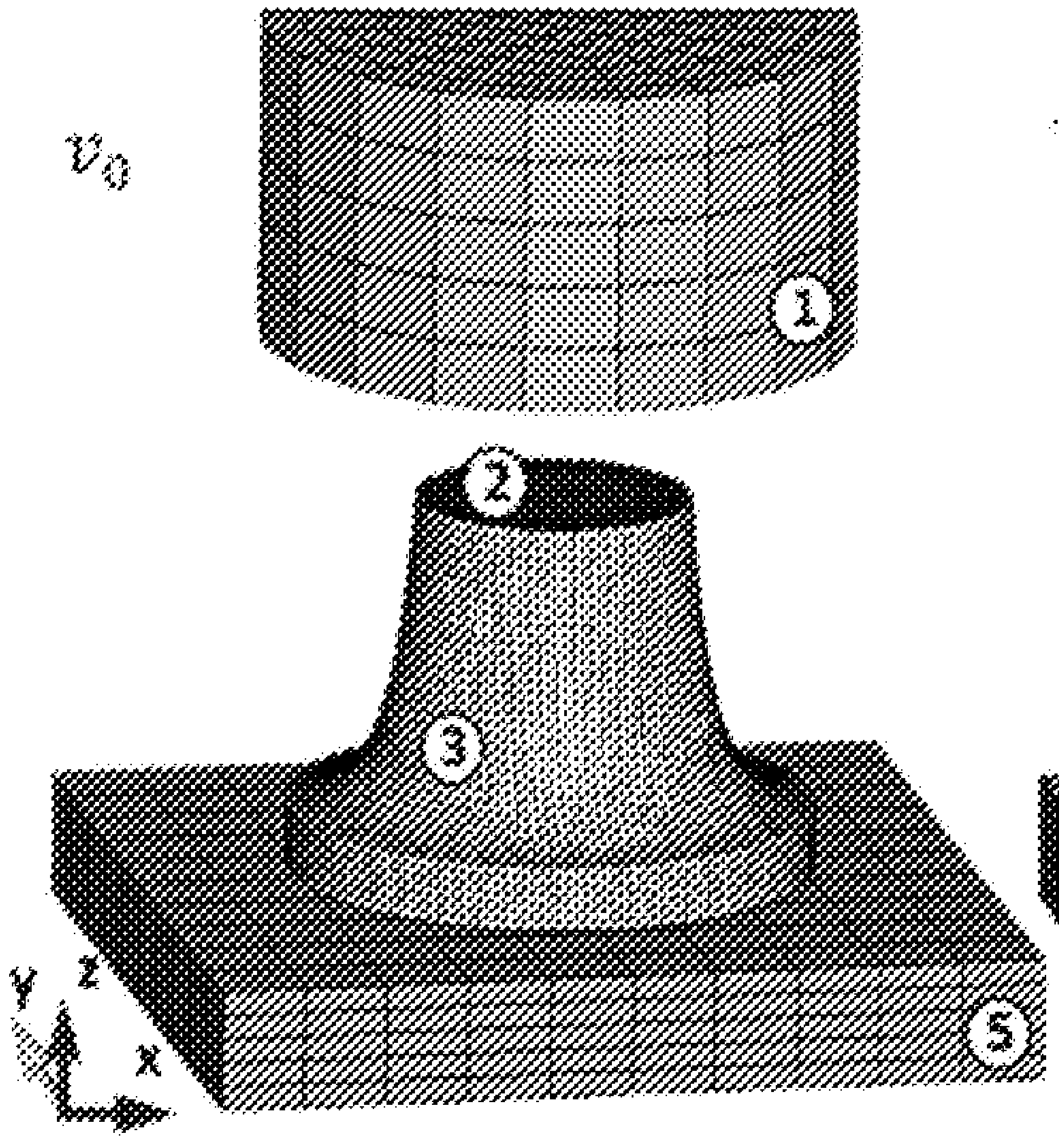


FIG. 15C

C. Cylindrical fluid damper

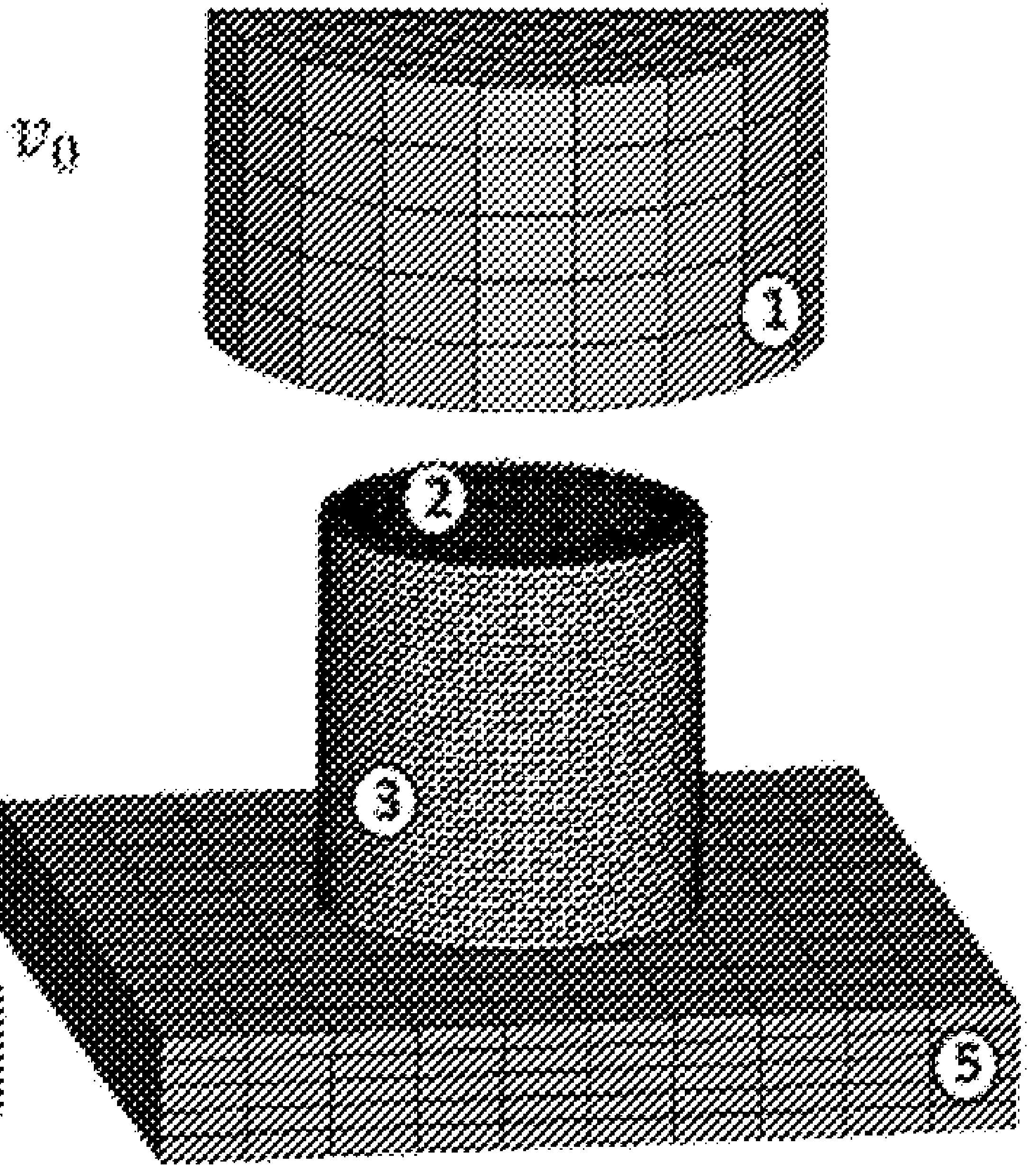


FIG. 15D

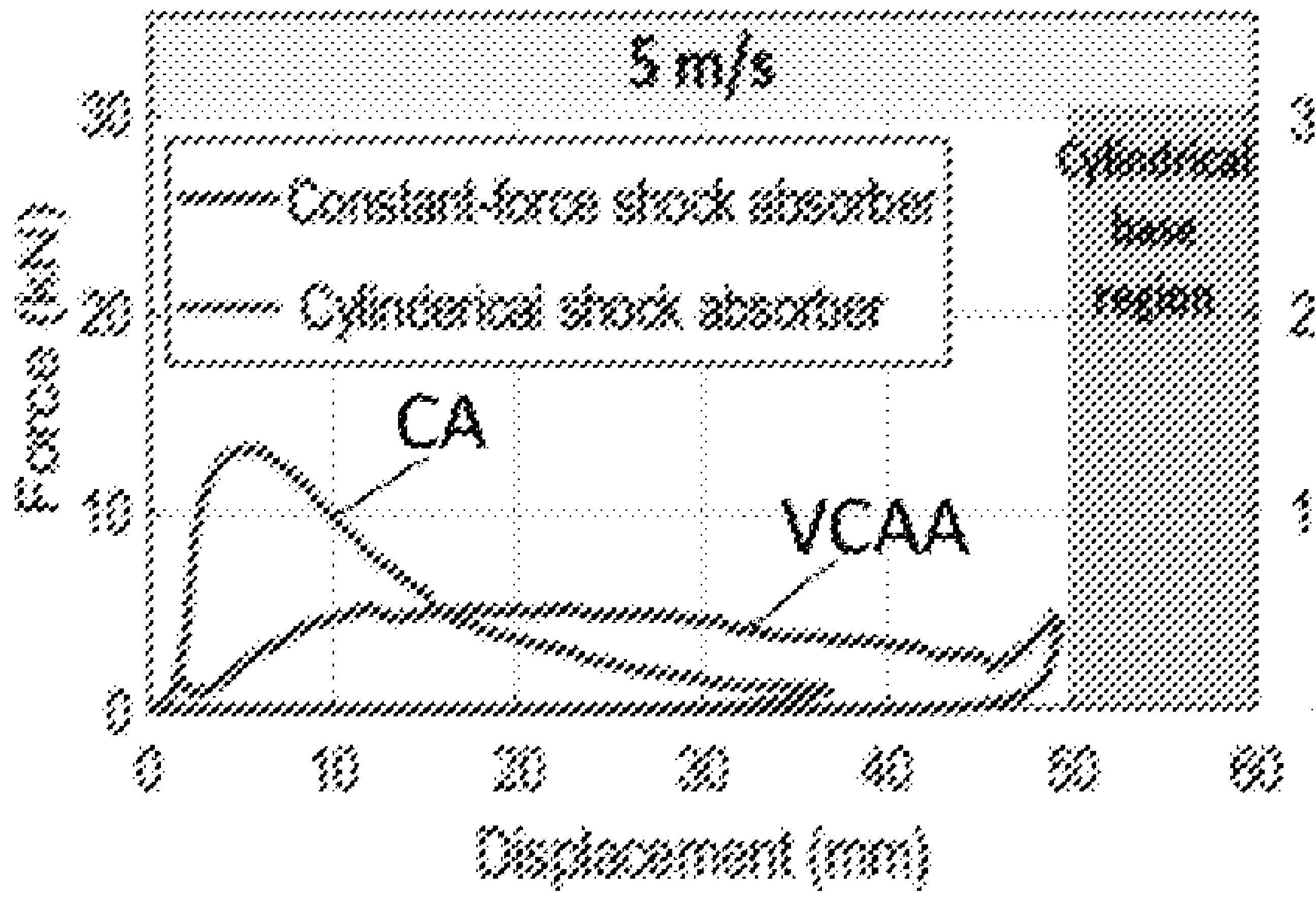


FIG. 15E

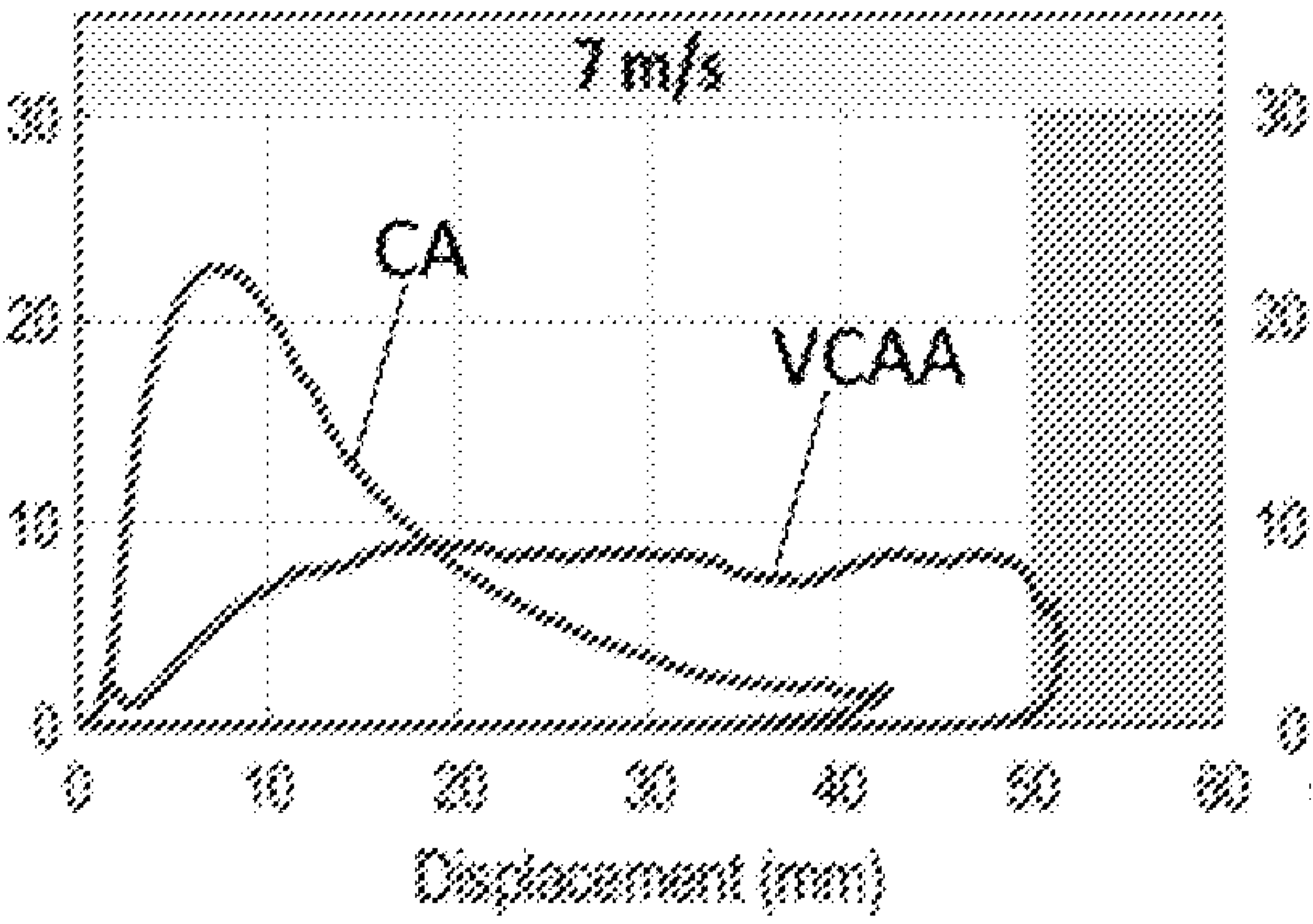


FIG. 15F

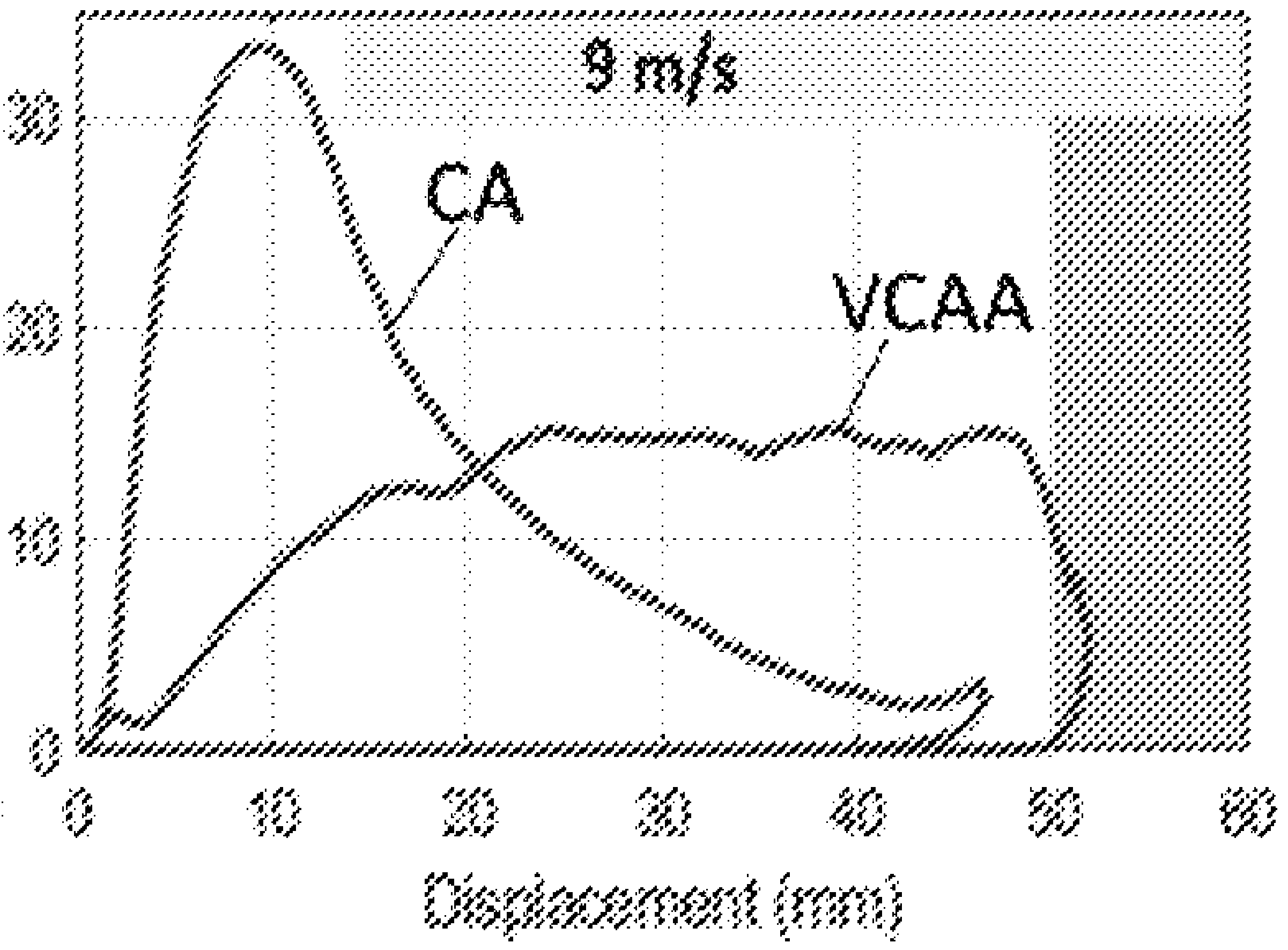


FIG. 15G

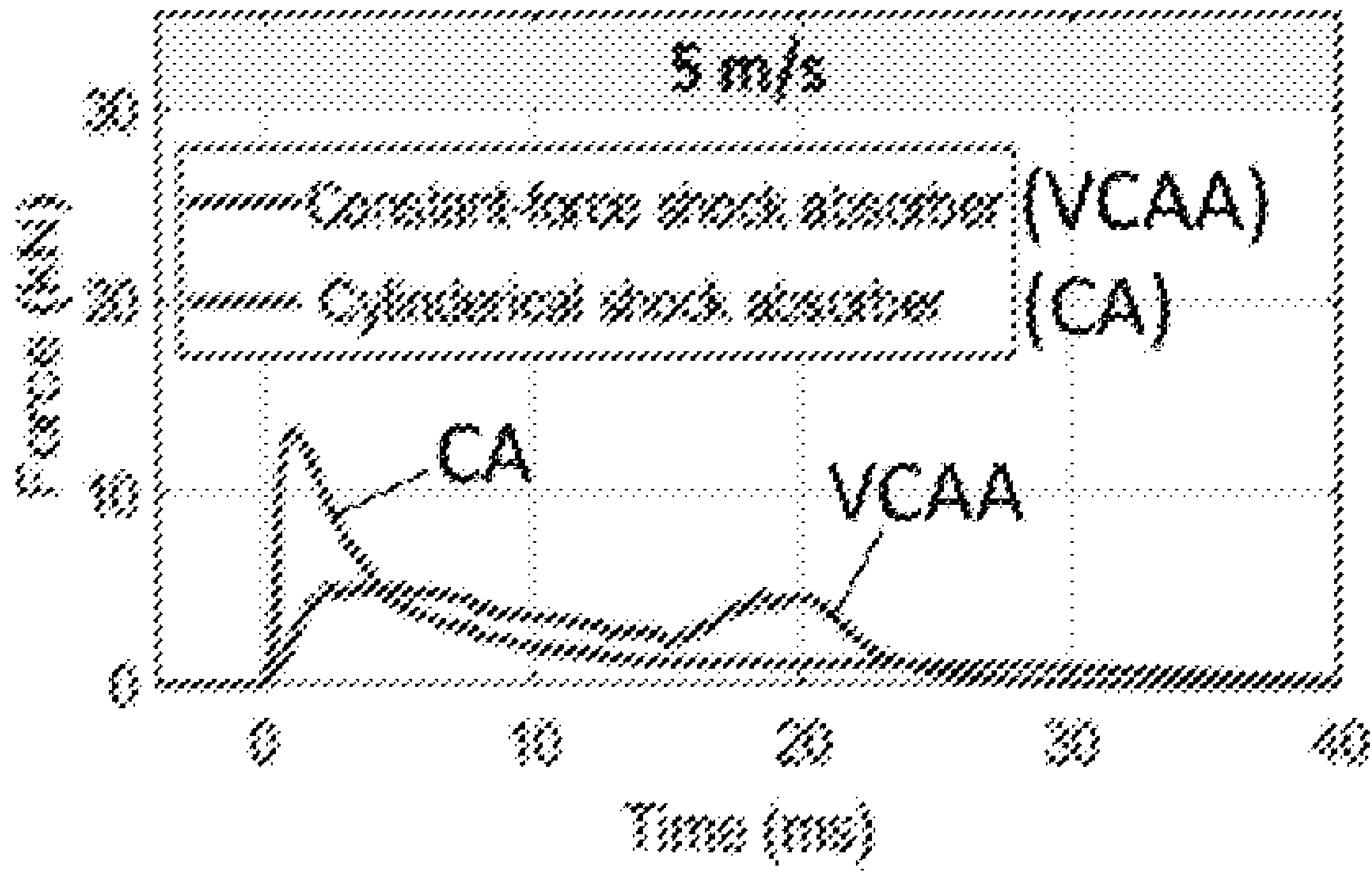


FIG. 15H

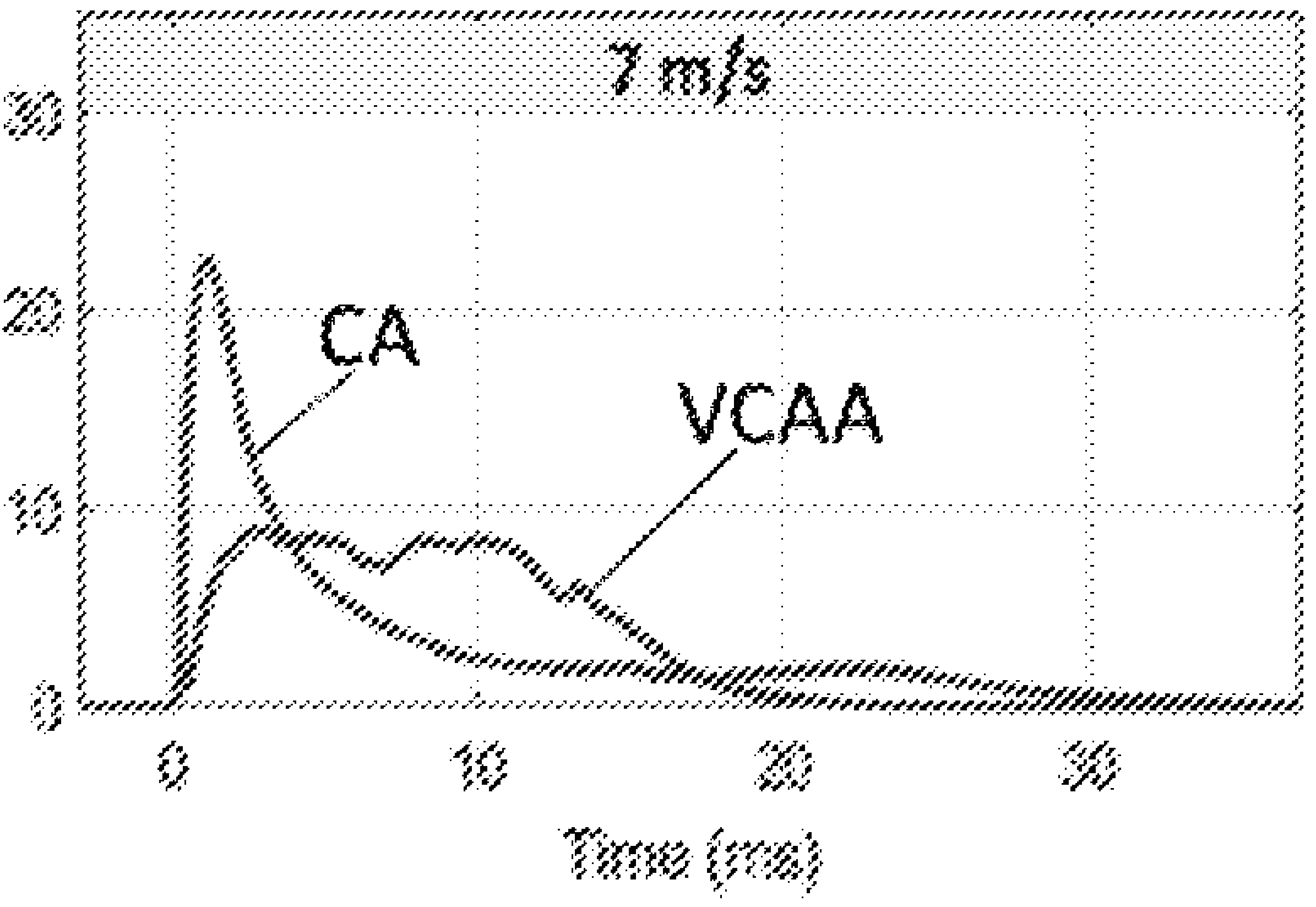


FIG. 15I

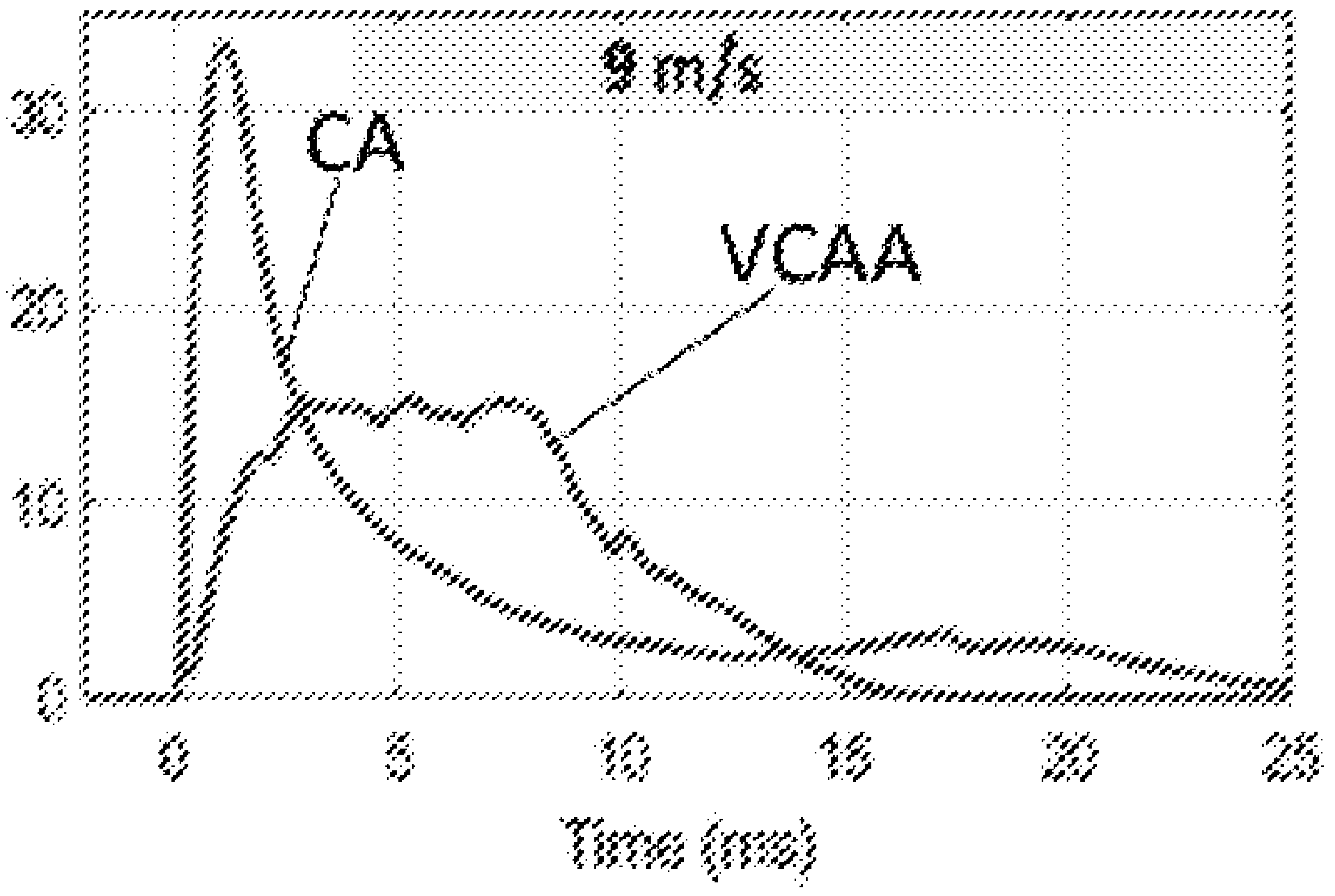


FIG. 15J

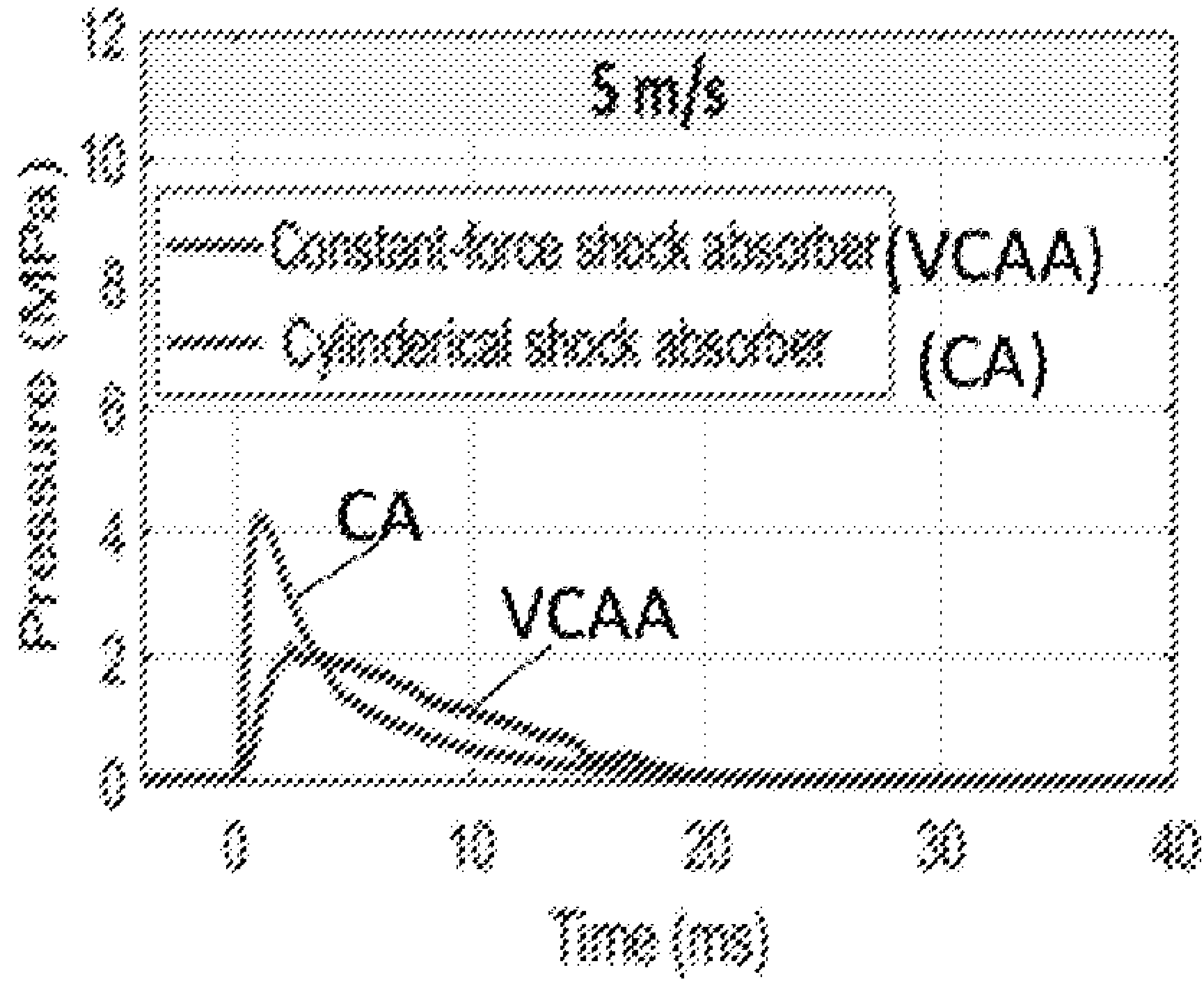


FIG. 15K

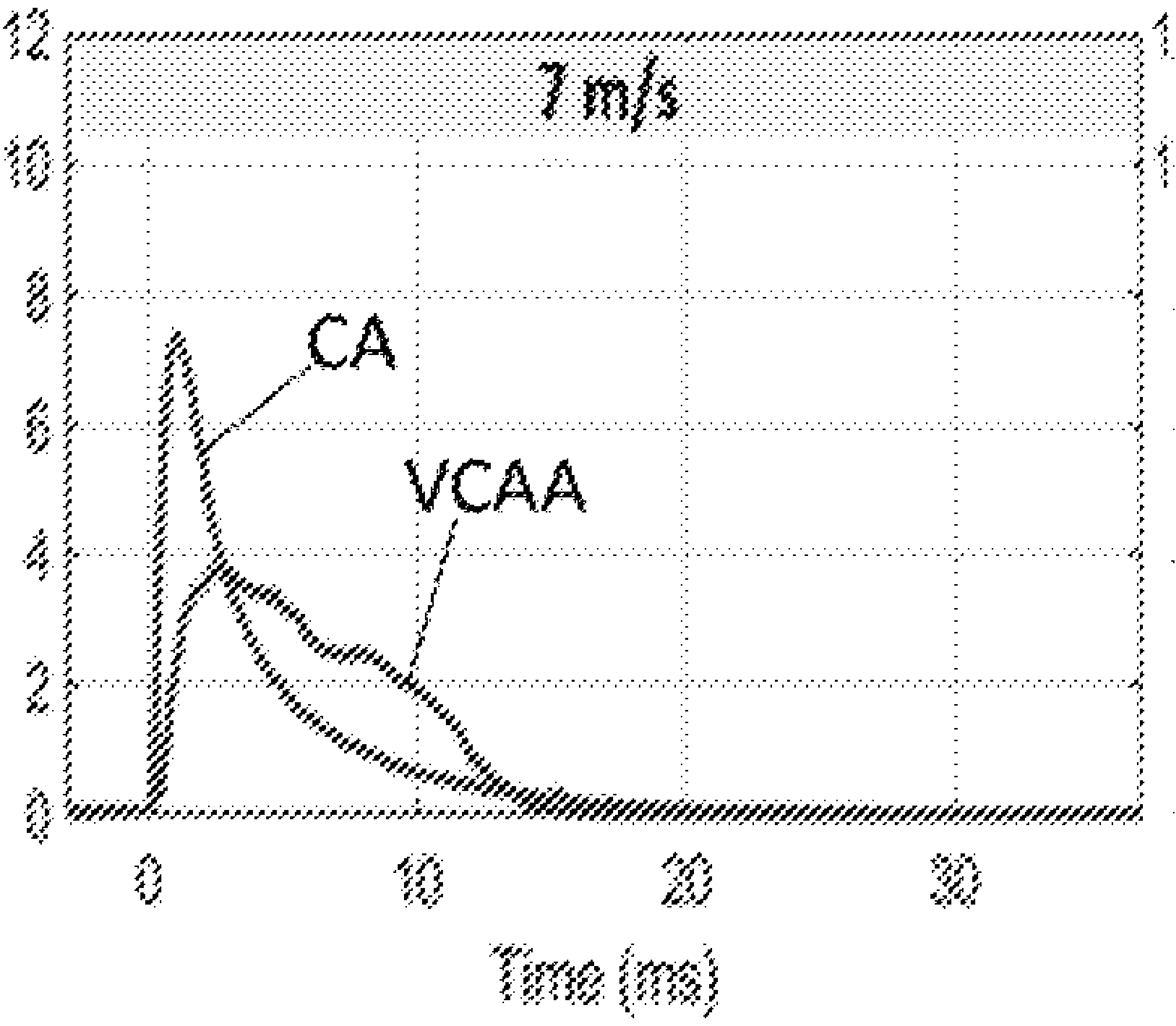


FIG. 15L

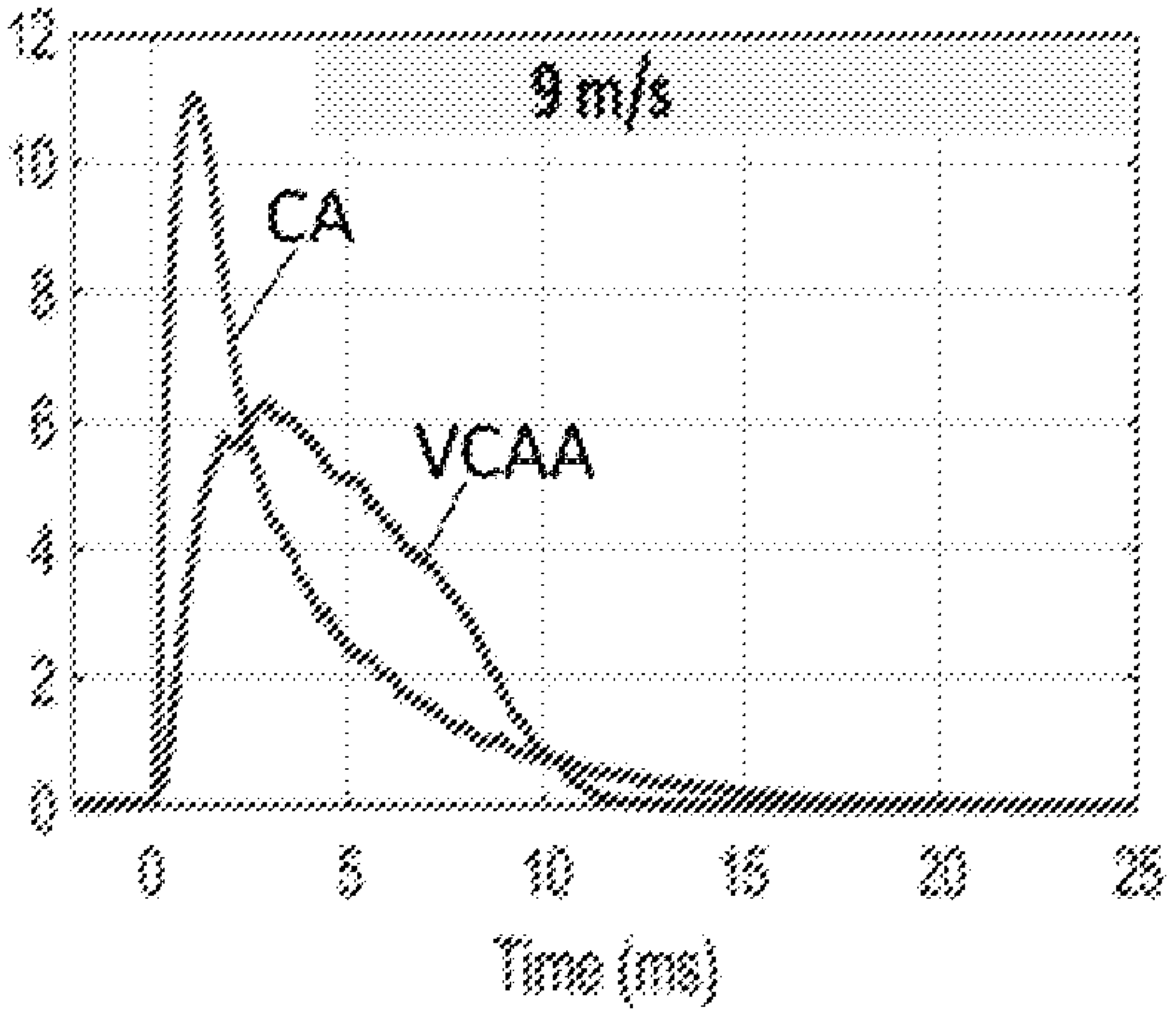


FIG. 15M

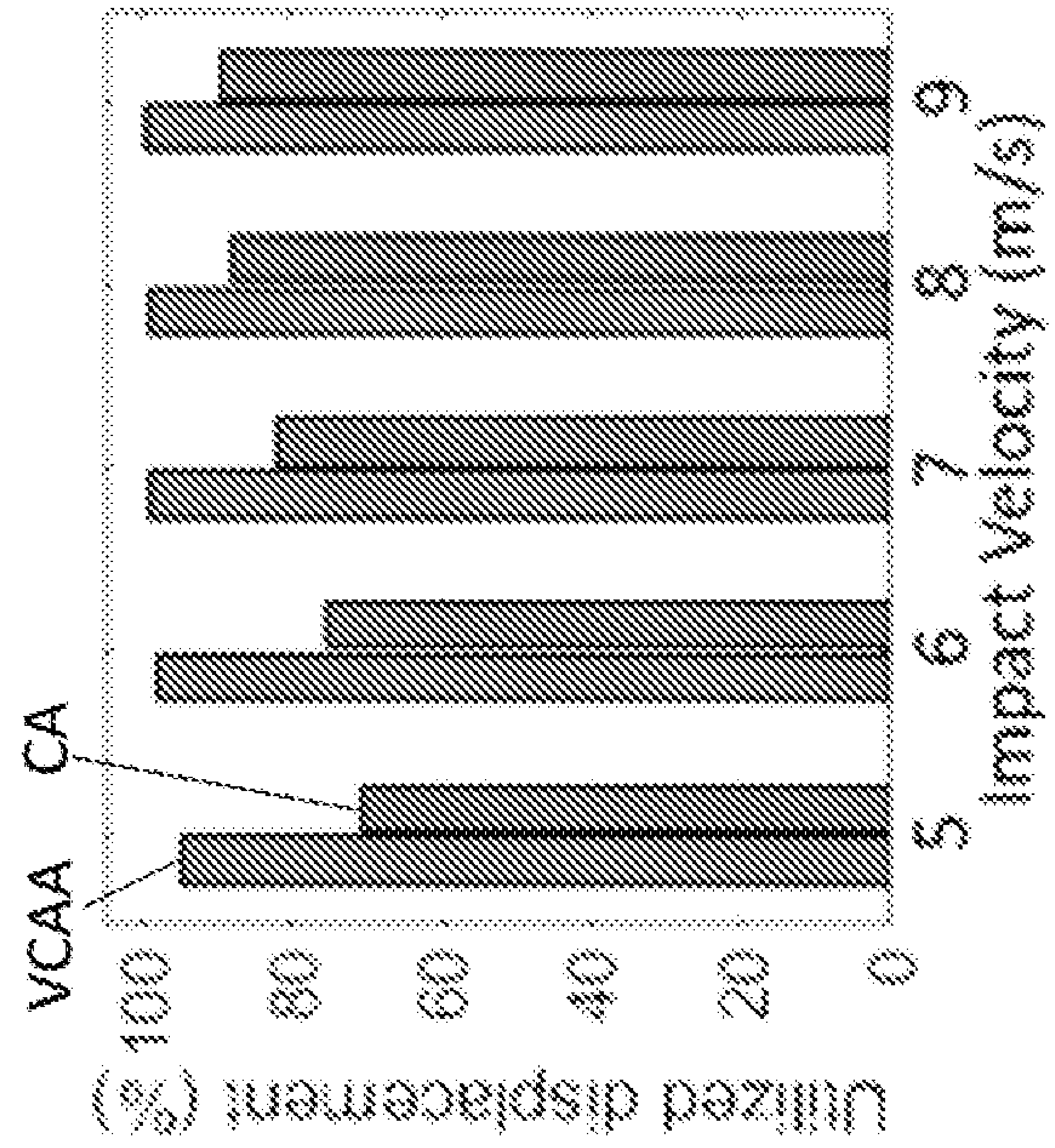


FIG. 16A

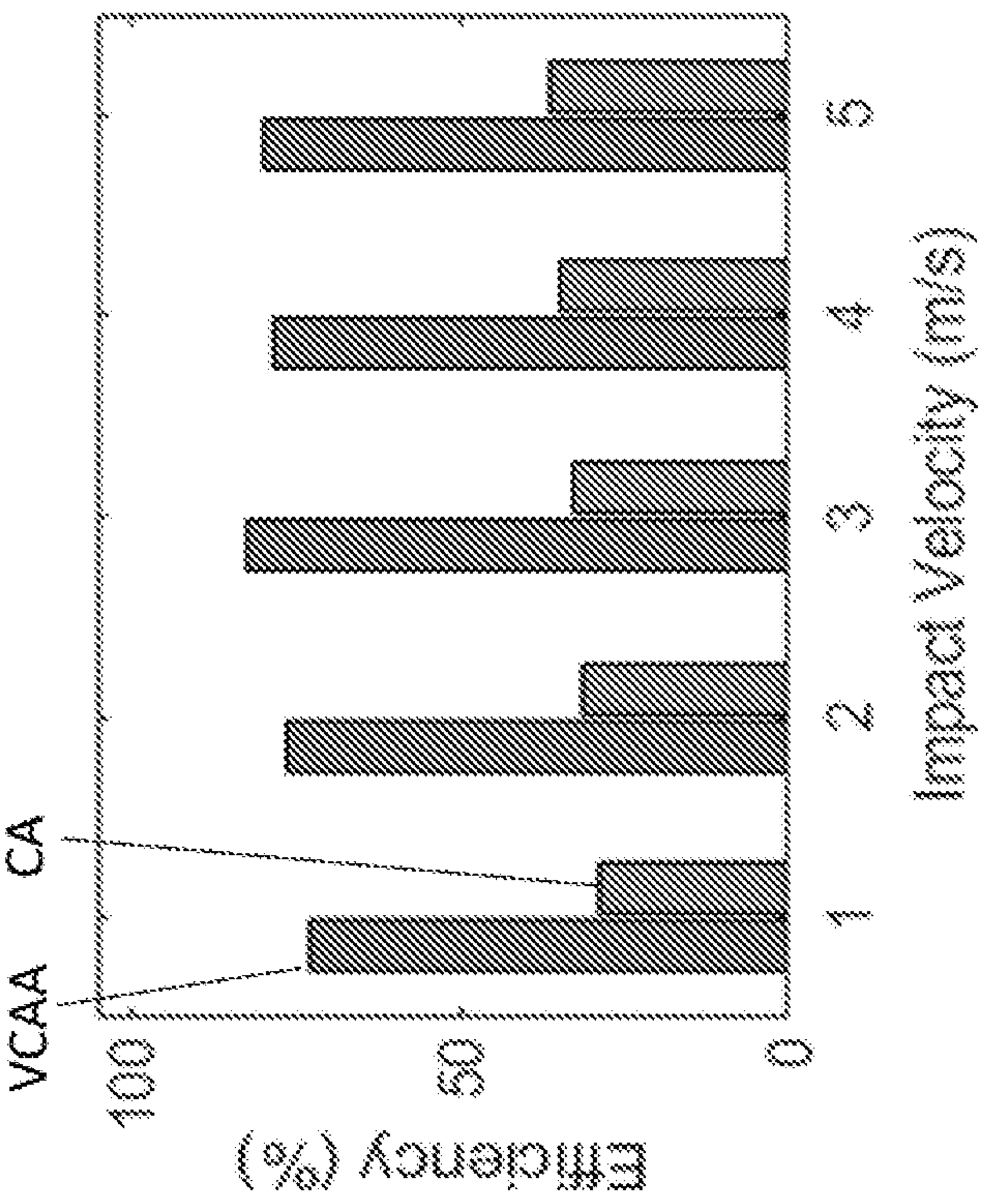


FIG. 16B

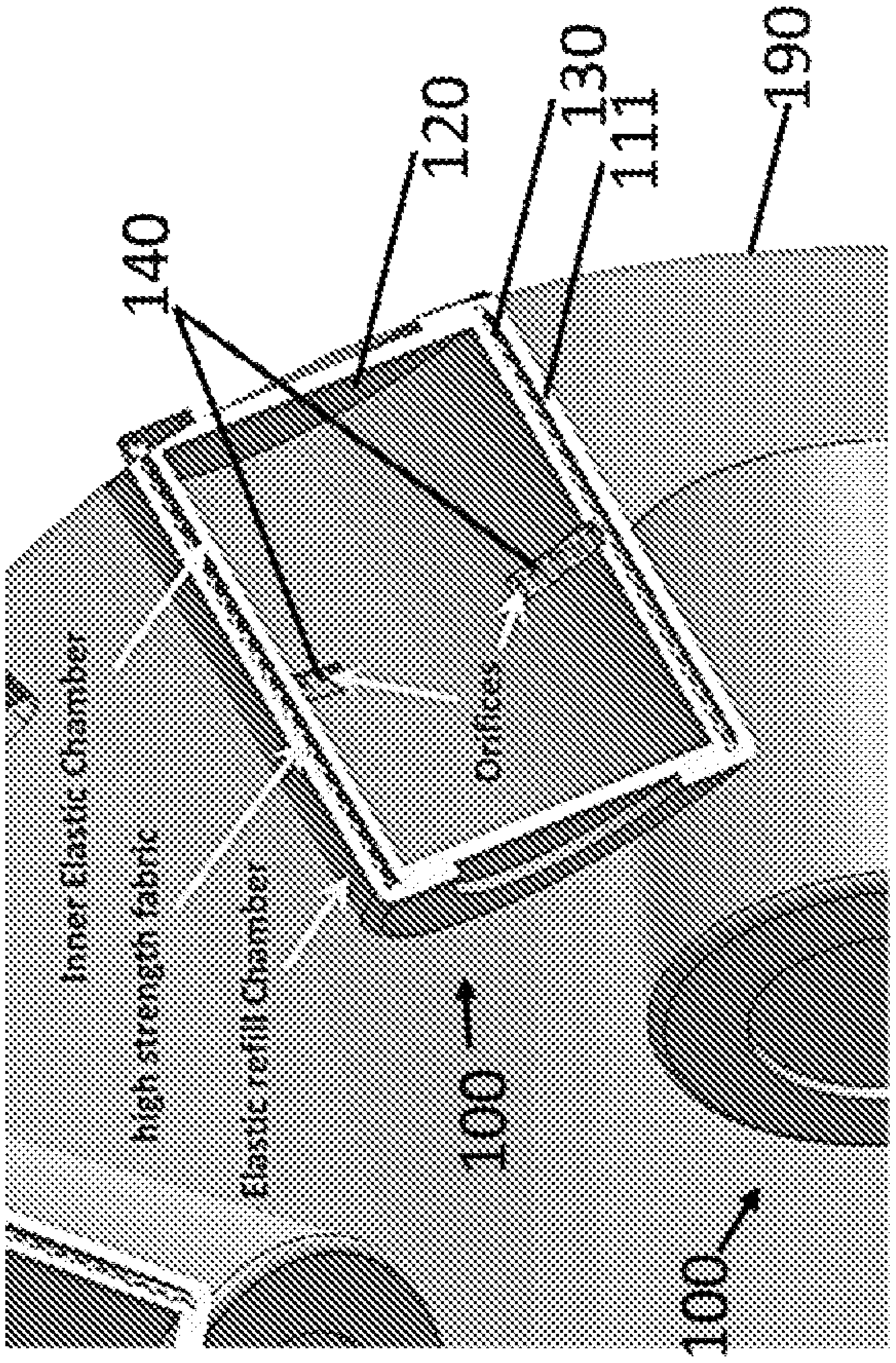


FIG 17B

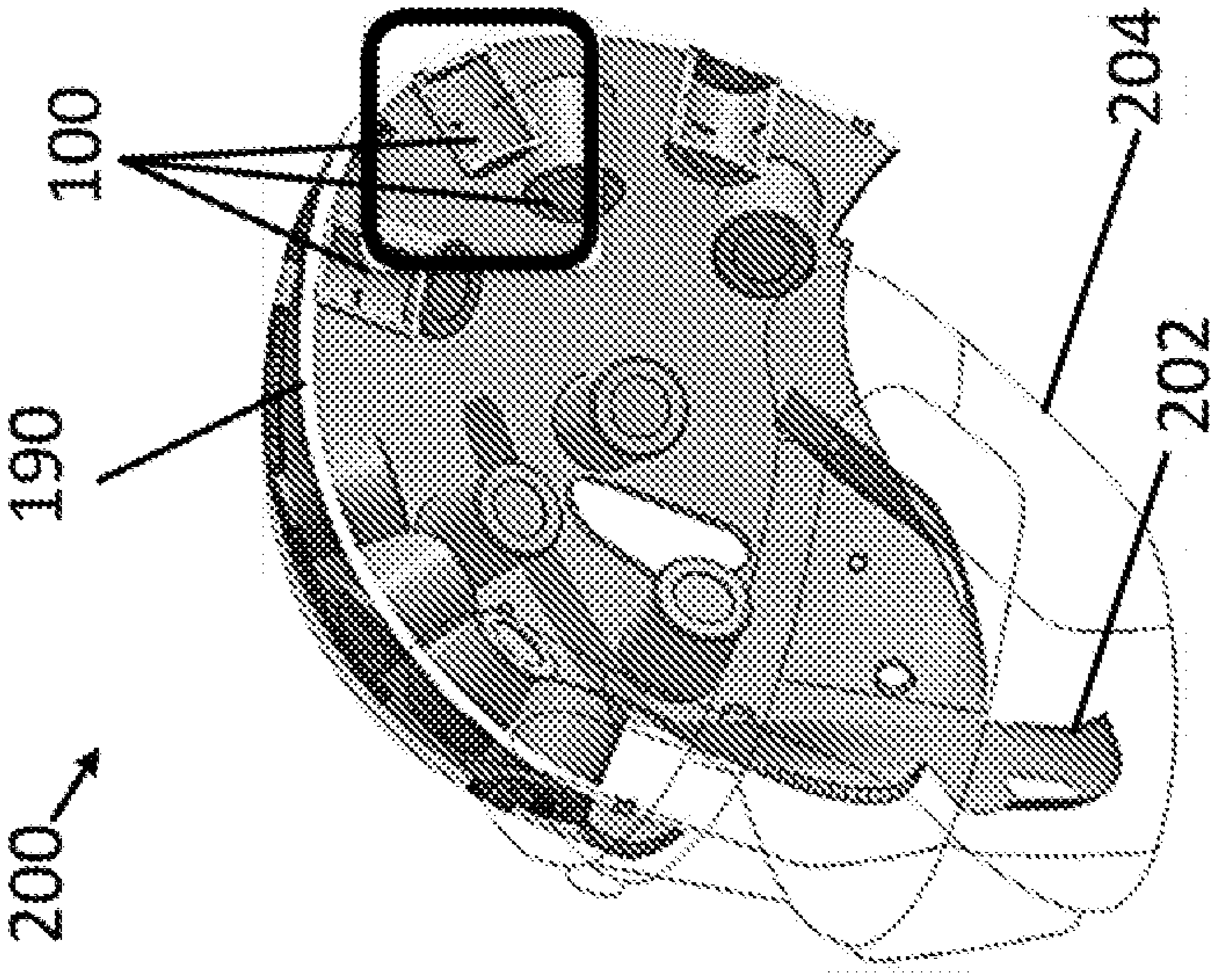


FIG. 17A

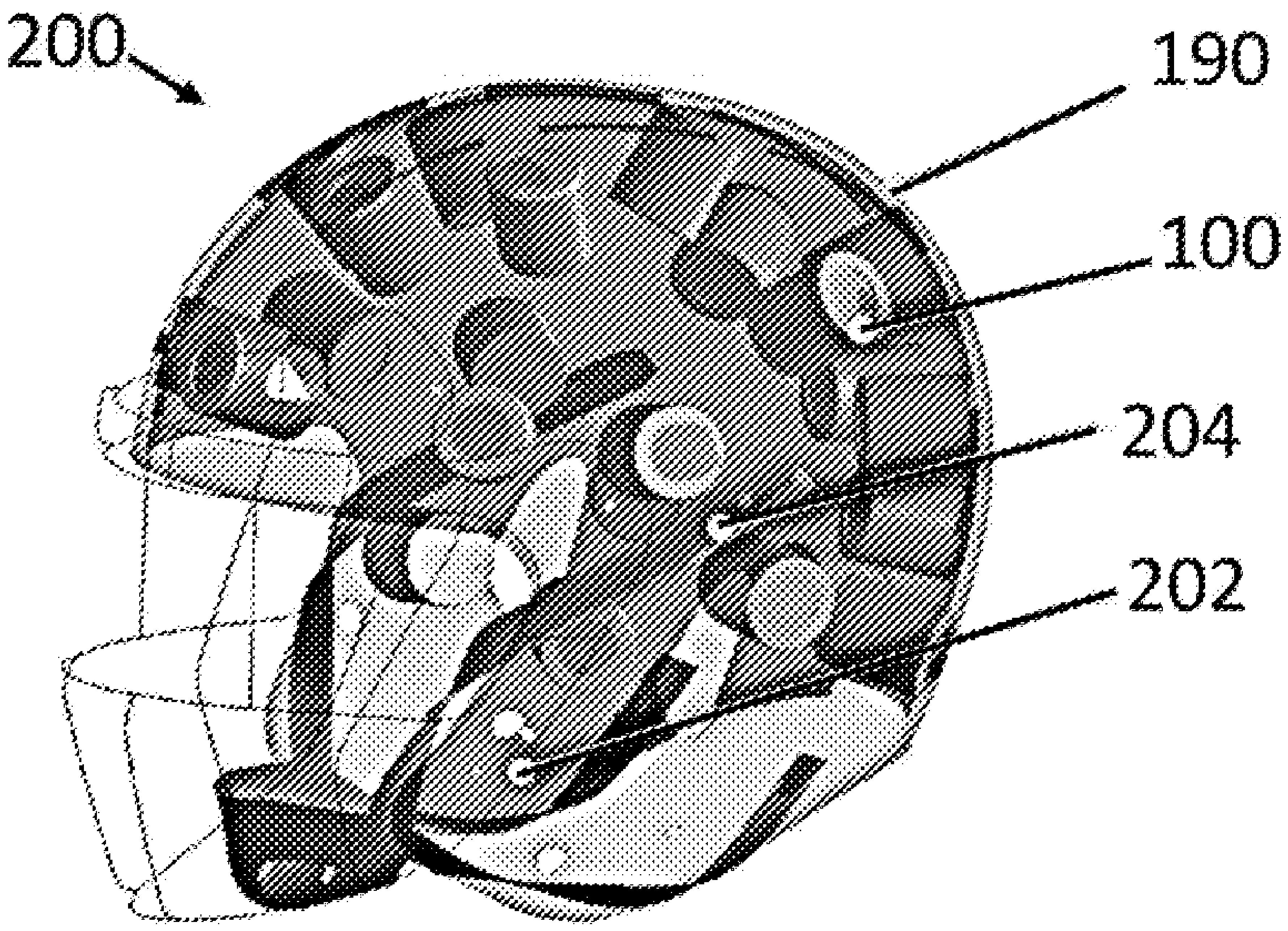


FIG. 17C

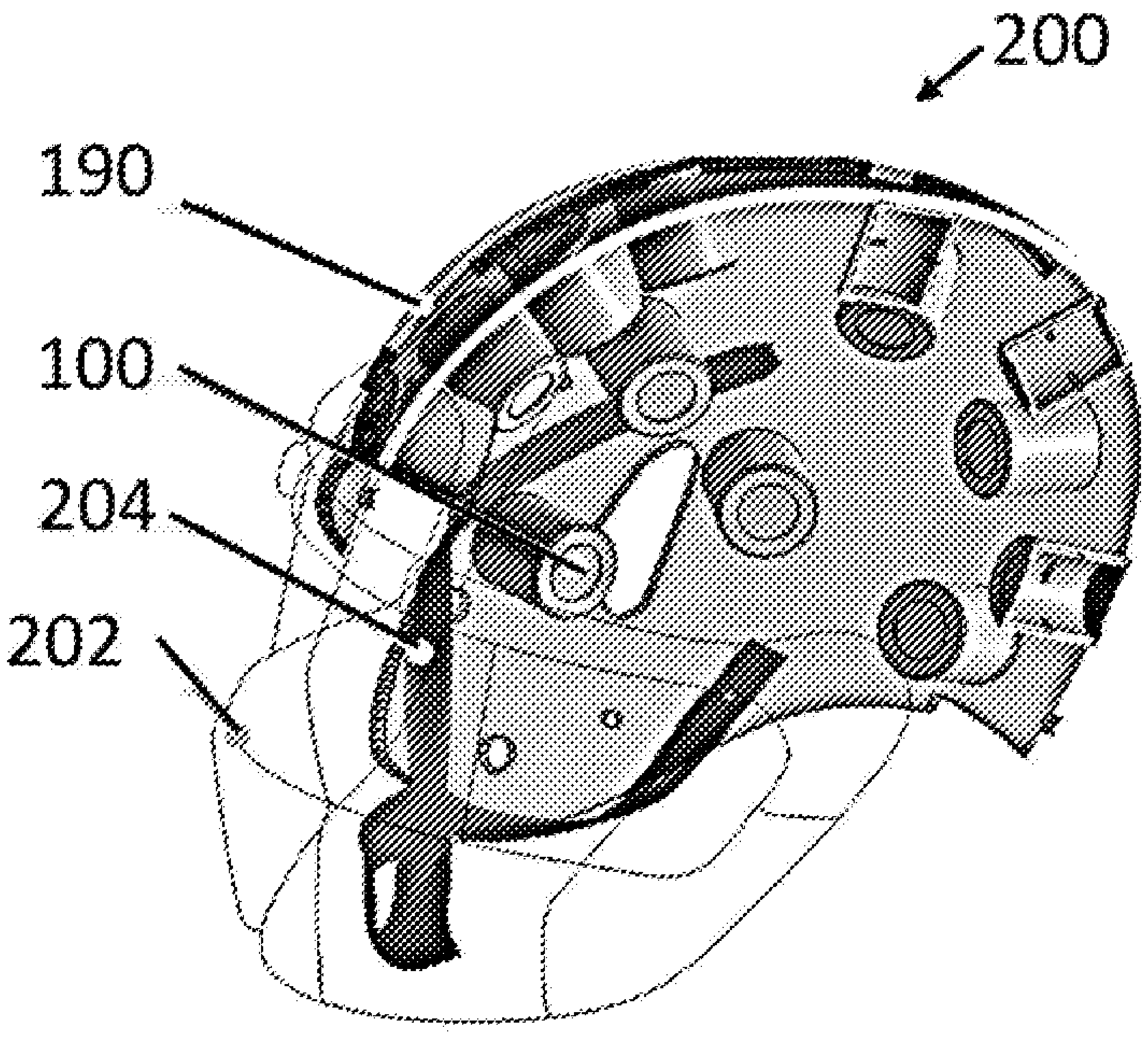


FIG 17D

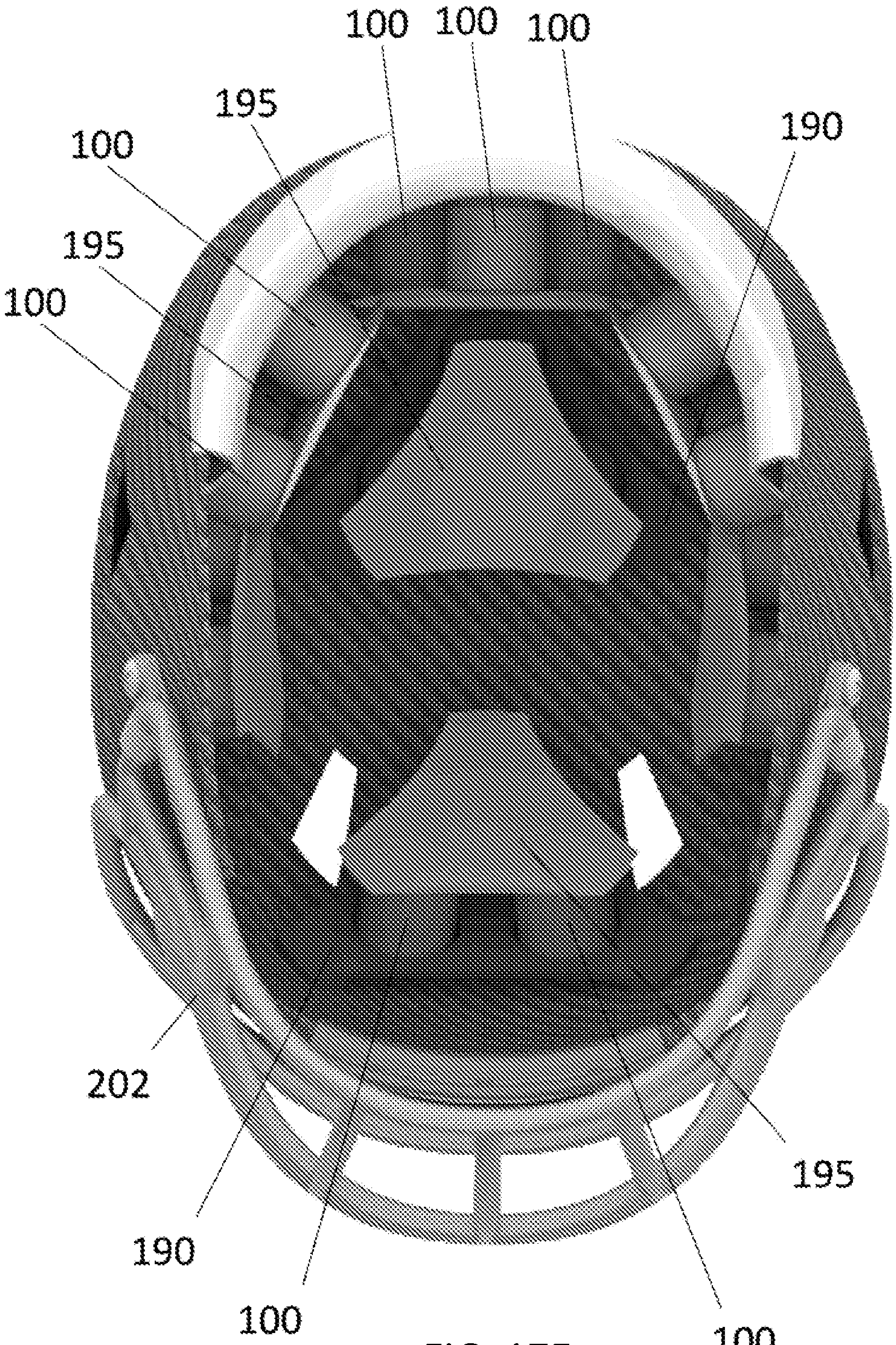


FIG. 17E

FIG. 18A

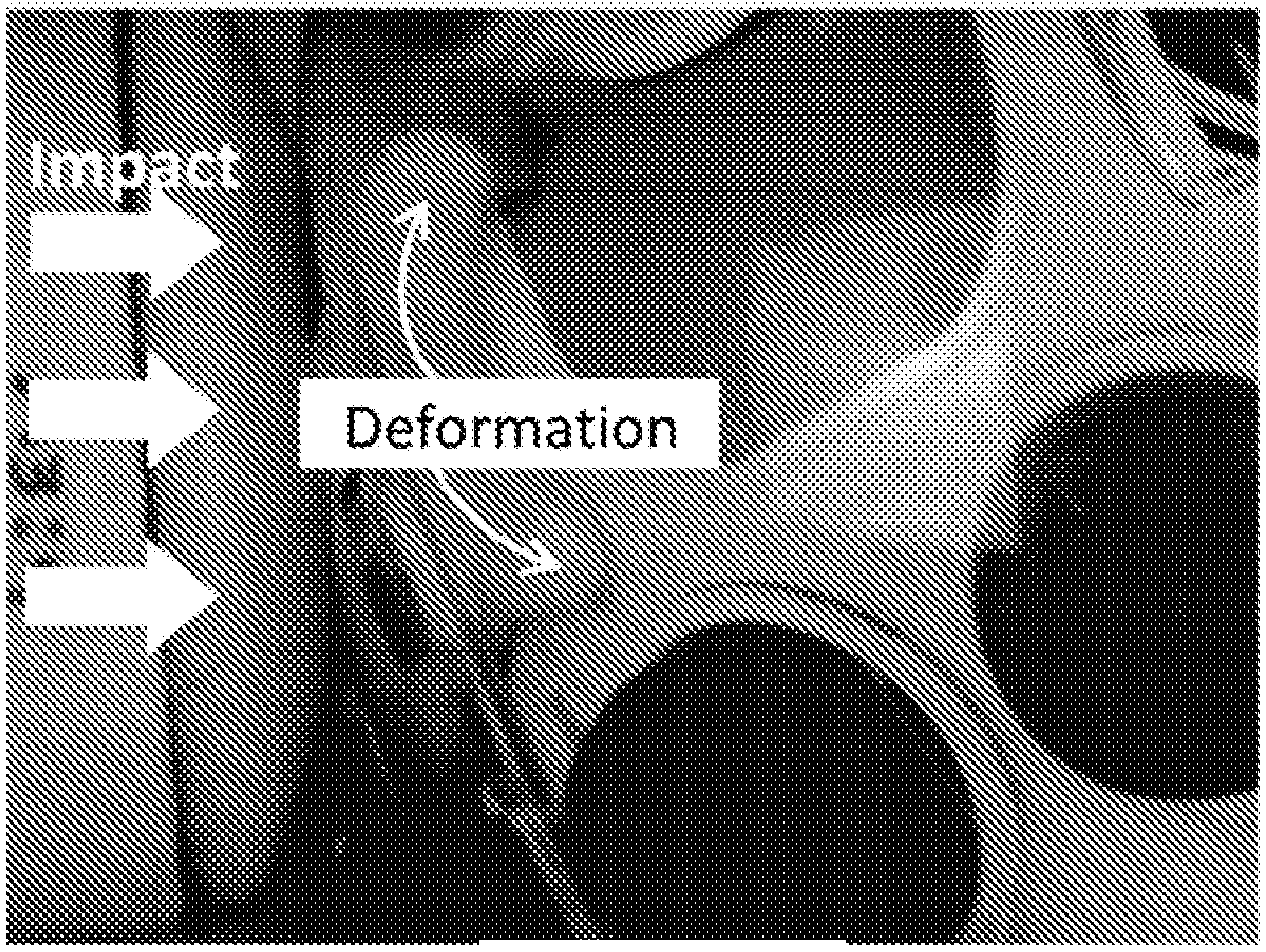
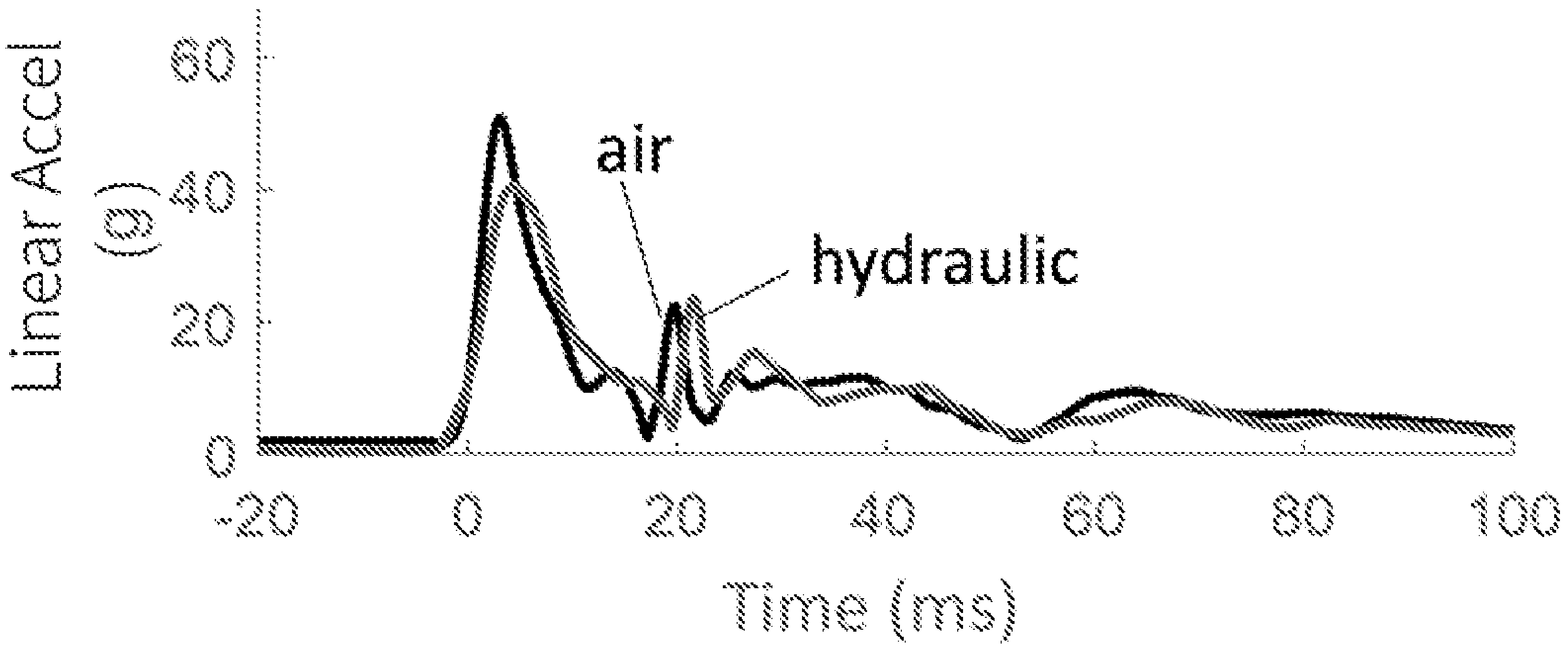


FIG. 18B

FIG. 18C



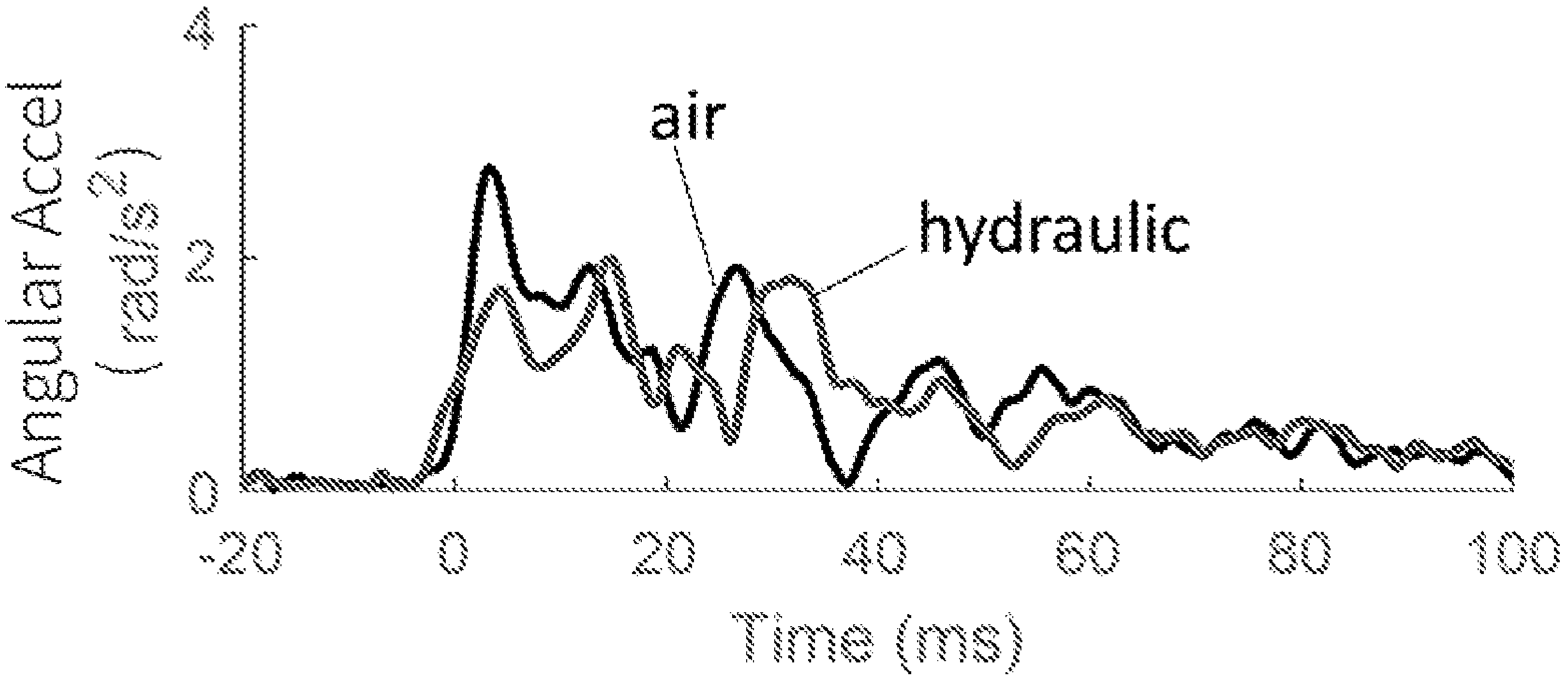
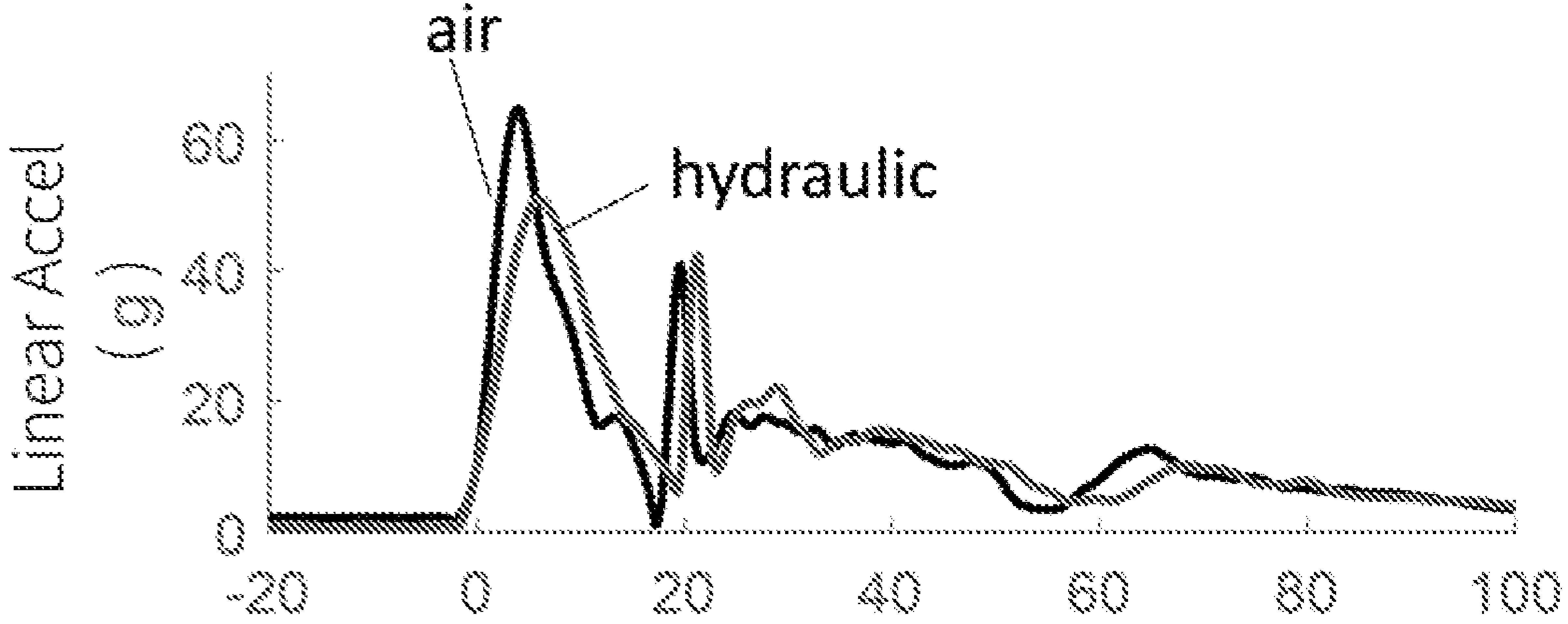


FIG. 18D

FIG. 18E



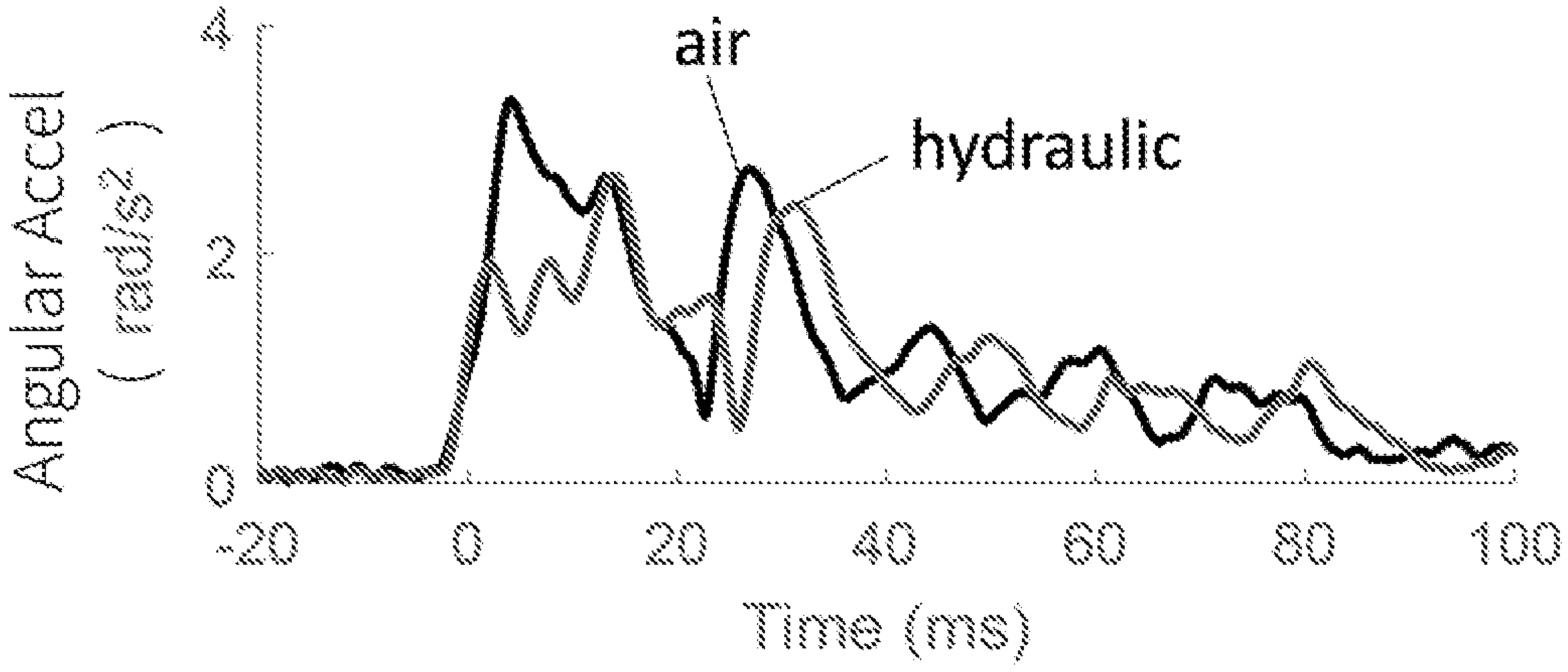


FIG. 18F

DEVICES, SYSTEMS AND METHODS FOR SHOCK ABSORPTION

FIELD OF THE INVENTION

The present invention generally relates to devices, systems, and methods for reducing the force experienced by an object and/or modulating the time over which the force is experienced by the object. In some cases, the present invention relates to devices, systems, and methods for reducing injury to a biological tissue (e.g. the skull and/or brain of a subject wearing a helmet).

BACKGROUND OF THE INVENTION

Mitigation of damage to biological tissues and inanimate objects as a result of physical impact is a complex technical challenge. Beyond absorption of physical forces acting on an impacted object, control of loading rate and energy dissipation are important to protecting the object from damage. Existing collapsible shock absorption systems do not have ideal force profiles under impact loading. For example, the force exerted by foams and existing personal protective equipment (PPEs) increases greatly as the material of the system is displaced under loading. In many cases, such as that of solid foam padding, the entire thickness of the collapsible energy absorber cannot be used to absorb or dissipate energy (e.g. due to compaction of the material). These systems are thus engineered for performance under high impact loading, leaving the systems too stiff to optimally absorb energy at lower force levels experience during low severity impacts.

Additionally, the shock absorption mechanisms used by traditional shock absorption devices typically have a rigid design, necessitating a great deal of space. For example, rigid shock absorption devices are more than double the size of their working stroke length. The space requirements of traditional rigid shock absorption devices can prohibit these devices from being deployed effectively in many space-constrained applications, such as equipment and systems that are small or portable (e.g. protective helmets), or that have configurations that do not allow incorporation of additional shock absorption equipment.

Thus, there exists a need for improved shock absorption devices and systems.

SUMMARY OF THE INVENTION

The present invention generally relates to devices, systems, and methods for reducing the force experienced by an object and/or modulating the time over which the force is experienced by the object. In some cases, the present invention relates to devices, systems, and methods for reducing injury to a biological tissue (e.g. the skull and/or brain of a subject wearing a helmet). Not necessarily all such aspects or advantages are achieved by any particular embodiment. Thus, various embodiments may be realized in a manner that achieves or optimizes one or more advantages or group of advantages taught herein without necessarily achieving other aspects or advantages as may also be taught or suggested herein.

Presented herein are devices for absorbing external impact forces, having: a collapsible elongated chamber having a first wall which resists circumferential expansion; a refill chamber at least partially enclosing an outer surface of the first wall of the collapsible elongated chamber, where the refill chamber is configured to expand in response to an internal pressure; a reservoir space disposed between an inner surface of a wall of the refill chamber and the outer surface of the first wall, where an interior of the collapsible elongated chamber is in bidirectional fluidic communication with the reservoir space via at least one orifice disposed through the first wall; and an incompressible fluid contained in the interior of the collapsible elongated chamber, where the reservoir space receives the incompressible fluid to expand the refill chamber as the incompressible fluid flows from the interior of the chamber through the at least one orifice when the chamber is compressed by the external impact forces, whereby the impact forces are absorbed or dissipated by the device. In some aspects, the wall of the refill chamber is configured to circumferentially expand outward in a substantially radial direction in response to the internal pressure. Presented herein are devices for absorbing energy, the apparatus having: a first chamber having a first wall surrounding an interior of the first chamber, the first wall having at least one orifice; a second chamber having a second wall, the second wall coupled to the first wall; and an incompressible fluid disposed within the first chamber, where the interior of the first chamber is in bidirectional fluid communication with an interstitial volume disposed between the outer surface of the first wall and an inner surface of the second wall via the at least one orifice. In some aspects, the second wall is coupled to an outer surface of the first wall. In some aspects, a wall of the refill chamber has an elastic material. In some aspects, the reservoir space is in bidirectional fluid communication with an interior of a first collapsible elongated chamber and an interior of a second collapsible elongated chamber. In some aspects, the incompressible fluid is water. In some aspects, the collapsible elongated chamber is axially collapsible. In some aspects, an orifice of the at least one orifice is disposed through the first wall at a proximal end of the collapsible elongated chamber. In some aspects, an orifice of the at least one orifice is disposed through the first wall at a proximal end of the collapsible elongated chamber. In some aspects, an orifice of the at least one orifice is disposed through the first wall between the proximal end and the distal end of the collapsible elongated chamber. In some aspects, an orifice of the at least one orifice has a cross-sectional area of from 1 mm^2 to 1,000 mm^2. In some aspects, the cross-sectional area of the collapsible elongated chamber decreases linearly along a longitudinal axis of the device, from a proximal end to a distal end. In some aspects, the cross-sectional area of the collapsible elongated chamber decreases non-linearly along a longitudinal axis of the device, from a proximal end to a distal end. In some aspects, the device further has a membrane disposed between the inner surface of the wall of the refill chamber and the outer surface of the first wall. In some aspects, the membrane is a high-strength material. In some aspects, the membrane has a permeable material. In some aspects, the membrane has an impermeable material. In some aspects, at least a portion of the membrane is mechanically isotropic. In some aspects, at least a portion of the membrane is mechanically anisotropic. In some aspects, the collapsible elongated chamber has an axial height of from 5 mm to 1,000 mm when undeformed. In some aspects, the collapsible elongated chamber has an axial height of from 10 mm to 50 mm when undeformed. In some aspects, the collapsible elongated chamber has a maximum width perpendicular to a longitudinal axis of from 10 mm to 50 mm when undeformed. In some aspects, a maximum width of a proximal end of the collapsible elongated chamber is from 5 mm to 60 mm when undeformed. In some aspects, a maximum width of a distal end of the collapsible elongated chamber is from 5 mm to 60 mm when undeformed. In some aspects, the device further has an elastically compressible material disposed within the first collapsible elongated chamber and coupled to an inner surface of the first wall at a proximal end of the device.

Presented herein are systems for absorbing external impact forces, having: a rigid support; and one or more force absorbing devices attached to the rigid support, at least one force absorbing device of the one or more force absorbing devices having: a collapsible elongated chamber having a first wall which resists circumferential expansion; a refill chamber at least partially enclosing an outer surface of the first wall of the collapsible elongated chamber, where the refill chamber is configured to expand in response to an internal pressure; a reservoir space disposed between an inner wall of the refill chamber and the outer surface of the first wall, where an interior of the chamber is in bidirectional fluidic communication with the reservoir space via at least one orifice disposed through the first wall, and an incompressible fluid contained in the interior of the collapsible elongated chamber, where the reservoir space receives the incompressible fluid to expand the refill chamber as the incompressible fluid flows from the interior of the chamber through the at least one orifice when the chamber is compressed by the external impact forces, whereby the impact forces are absorbed or dissipated by the device. In some aspects, the rigid support is permanently coupled to a proximal end of at least one force absorbing device of the one or more force absorbing devices. In some aspects, the rigid support is removably coupled to a proximal end of at least one force absorbing device of the one or more force absorbing devices. In some aspects, the system further has a plurality of force absorbing devices. In some aspects, further has a second support coupled to a distal end of at least one apparatus of the plurality of apparatuses. In some aspects, the second support is coupled to a distal end of each of the plurality of force absorbing devices. In some aspects, the reservoir space is in bidirectional fluid communication with an interior of a first collapsible elongated chamber and an interior of a second collapsible elongated chamber. In some aspects, the rigid support is a helmet shell. In some aspects, the wall of the refill chamber is configured to circumferentially expand outward in a substantially radial direction in response to the internal pressure. In some aspects, the reservoir space is in bidirectional fluid communication with an interior of a first collapsible elongated chamber and an interior of a second collapsible elongated chamber. In some aspects, an orifice of the at least one orifice is disposed through the first wall at a proximal end of the collapsible elongated chamber. In some aspects, an orifice of the at least one orifice has a cross-sectional area of from 1 mm^2 to 1,000 mm^2. In some aspects, the cross-sectional area of the collapsible elongated chamber decreases linearly along a longitudinal axis of the device, from a proximal end to a distal end. In some aspects, the cross-sectional area of the collapsible elongated chamber decreases non-linearly along a longitudinal axis of the device, from a proximal end to a distal end. In some cases, the system further has a fabric disposed between the inner surface of the wall of the refill chamber and the outer surface of the first wall. In some aspects, the collapsible elongated chamber has an axial height of from 10 mm to 50 mm when undeformed. In some aspects, the collapsible elongated chamber has a maximum width perpendicular to a longitudinal axis of from 10 mm to 50 mm when undeformed. In some aspects, a maximum width of a proximal end of the collapsible elongated chamber is from 5 mm to 60 mm when undeformed. In some aspects, a maximum width of a distal end of the collapsible elongated chamber is from 5 mm to 60 mm when undeformed. In some aspects, the collapsible elongated chamber is axially collapsible. In some aspects, the system further has an elastically compressible material coupled the solid support. In some aspects, the elastically compressible material is disposed adjacent to the proximal end of at least one of the one or more force absorbing devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A shows an exterior view of an energy absorption device, in accordance with embodiments.

FIG. **1**B shows a cut-away view of the energy absorption device of FIG. **1**A.

FIG. **2**A shows an exterior view of an energy absorption device, in accordance with embodiments.

FIG. **2**B shows a cut-away view of the energy absorption device of FIG. **2**A.

FIG. **2**C shows an exploded view of the energy absorption device of FIG. **2**A.

FIG. **2**D shows a cut-away view of exploded view of the energy absorption device shown in FIG. **2**C.

FIG. **2**E shows a further exploded view of the energy absorption device shown in FIG. **2**D.

FIG. **3**A is a schematic of an energy absorption device, in accordance with embodiments.

FIG. **3**B is a schematic of the energy absorption device shown in FIG. **3**B under axial loading, in accordance with embodiments.

FIG. **3**C is a photograph of an undeformed energy absorption device, in accordance with embodiments.

FIG. **3**D is a photograph of the energy absorption device shown in FIG. **3**C during axial loading, in accordance with embodiments.

FIGS. **4**A-C show schematics of an energy absorption device, as it deforms under axial loading from a mass (m), in accordance with embodiments.

FIG. **4**D illustrates changes in contact area of some apparatuses for absorbing energy described herein as a function of axial displacement of an axially loaded apparatus surface, in accordance with embodiments.

FIGS. **5**A-D show side views of apparatuses for absorbing energy, in accordance with embodiments.

FIG. **6**A shows a cross-sectional schematic of an undeformed energy absorption device, in accordance with embodiments.

FIG. **6**B shows a cross-sectional schematic of a deformed energy absorption device, in accordance with embodiments.

FIG. **7**A shows a partial cut-away view of an energy absorption device, in accordance with embodiments.

FIG. **7**B shows a partial cut-away view of an energy absorption device, in accordance with embodiments.

FIG. **7**C shows a cross-sectional view of an energy absorption device, in accordance with embodiments.

FIG. **8**A shows a side view of a pressure chamber of an energy absorption device, in accordance with embodiments.

FIG. **8**B shows a top view of the pressure chamber of FIG. **8**A, in accordance with embodiments.

FIG. **8**C shows a side view of a pressure chamber of an energy absorption device, in accordance with embodiments.

FIG. **8**D shows a top view of the pressure chamber of FIG. **8**C, in accordance with embodiments.

FIG. **8**E shows a side view of a pressure chamber of an energy absorption device, in accordance with embodiments.

FIG. **8**F shows a top view of the pressure chamber of FIG. **8**E, in accordance with embodiments.

FIG. **8**G shows a side view of a pressure chamber of an energy absorption device, in accordance with embodiments.

FIG. **8**H shows a top view of the pressure chamber of FIG. **8**G, in accordance with embodiments.

FIG. **8**I shows a side view of a pressure chamber of an energy absorption device, in accordance with embodiments.

FIG. **8**J shows a top view of the pressure chamber of FIG. **8**I, in accordance with embodiments.

FIG. **9**A shows a pressure chamber comprising orifices, in accordance with embodiments.

FIG. **9**B shows an energy absorption device comprising a third chamber, in accordance with embodiments.

FIG. **10**A shows finite element model data for axial loading of an energy absorption device, in accordance with embodiments.

FIG. **10**B shows finite element model data for effects of orifice size during axial loading of an energy absorption device, in accordance with embodiments.

FIG. **11**A shows effects of orifice size on measured changes in acceleration over time in an object equipped with an energy absorption device after a 50 cm drop, in accordance with embodiments.

FIG. **11**B shows effects of orifice size on measured force-displacement curves for an energy absorption device, in accordance with embodiments.

FIG. **12**A shows illustrates the relationship between force and percent displacement of a foam shock absorber (gray curve) and the relationship between force and percent displacement of an idealized rigid shock absorber (horizontal line), in accordance with embodiments.

FIG. **12**B shows experimental force-displacement data for a 3.1 m/s impact to a foam shock absorber (foam), a bucking cone shock absorber (cone), an air damper (air), and an energy absorption device disclosed herein (**100**), in accordance with embodiments.

FIG. **12**C shows experimental force-displacement data for a 4.3 m/s impact to a foam shock absorber (foam), a bucking cone shock absorber (cone), an air damper (air), and an energy absorption device disclosed herein (**100**), in accordance with embodiments.

FIG. **12**D shows experimental force-displacement data for a 5.5 m/s impact to a foam shock absorber (foam), a bucking cone shock absorber (cone), an air damper (air), and an energy absorption device disclosed herein (**100**), in accordance with embodiments.

FIGS. **13**A-C show experimental (Exp) and finite element simulation (FE) results for variable contact area apparatus (VCAA) under axial loading rates of 3.1 m/s (FIG. **13**A), 4.3 m/s (FIG. **13**B), and 5.5 m/s (FIG. **13**C), in accordance with embodiments.

FIG. **14**A shows a cylindrical coordinate plot of dimensions of a variable contact area apparatus (VCAA) in cross-section, in accordance with embodiments.

FIG. **14**B shows computer modeling of the relationships between contact area, force exerted by the VCAA, and pressure exerted by the VCAA for axial loading of a variable contact area apparatus, in accordance with embodiments.

FIG. **14**C shows computer modeling of the force-to-initial impact velocity relationship for axial loading of a variable contact area apparatus, in accordance with embodiments.

FIG. **14**D shows relationships between exerted constant force and time at various impact velocities for axial loading of a variable contact area apparatus, in accordance with embodiments.

FIG. **15**A shows a schematic of a variable contact area apparatus (VCAA) for absorbing energy comprising solid endcaps, in accordance with embodiments.

FIG. **15**B shows an exploded view of a cross-section of the energy absorption device shown in FIG. **15**A, in accordance with embodiments.

FIG. **15**C shows a finite element (FE) model for determining force and pressure dynamics of the energy absorption device shown in FIG. **15**A under axial loading, in accordance with embodiments.

FIG. **15**D shows a finite element model for determining loading dynamics of a cylindrical apparatus (CA) for absorbing energy under axial loading, in accordance with embodiments.

FIGS. **15**E-G show force-displacement relationships for variable contact area apparatus (VCAA) and cylindrical apparatus (CA) under axial loading rates of 5 m/s (FIG. **15**E), 7 m/s (FIG. **15**F), and 9 m/s (FIG. **15**G) in finite element simulation experiments described in FIGS. **15**A-**15**D, in accordance with embodiments.

FIGS. **15**H-J show force-time relationships for variable contact apparatus (VCAA) and cylindrical apparatus (CA) under axial loading rates of 5 m/s (FIG. **1511**), 7 m/s (FIG. **15**I), and 9 m/s (FIG. **15**J) in finite element simulation experiments described in FIGS. **15**A-**15**D, in accordance with embodiments.

FIGS. **15**K-M show pressure-time relationships for variable contact apparatus (VCAA) and cylindrical apparatus (CA) under axial loading rates of 5 m/s (FIG. **15**K), 7 m/s (FIG. **15**L), 9 m/s (FIG. **15**M), in accordance with embodiments.

FIG. **16**A shows percent utilized displacement of variable contact area apparatus (VCAA) and cylindrical apparatus (CA) at various impact velocities determined by computer modeling, in accordance with embodiments.

FIG. **16**B shows a comparison of shock absorption efficiency for VCAA, CA, and foam shock absorption devices, in accordance with embodiments

FIG. **17**A shows a system comprising a plurality of apparatuses for absorbing energy, in accordance with embodiments.

FIG. **17**B shows a magnified view of a portion of the system for absorbing energy indicated by the black box in FIG. **17**A.

FIG. **17**C shows a system comprising a plurality of apparatuses for absorbing energy, in accordance with embodiments.

FIG. **17**D shows a cut-away view of the system of FIG. **17**C, in accordance with embodiments.

FIG. **17**E shows a schematic of a system comprising a plurality of pressure distribution plates, in accordance with embodiments.

FIG. **18**A is a photograph of an athletic helmet equipped with an energy absorption device, in accordance with embodiments.

FIG. **18**B is a photograph of the energy absorption device show in FIG. **18**A during impact testing, in accordance with embodiments.

FIG. **18**C shows linear acceleration data collected from impact testing shown in FIG. **18**A and FIG. **18**B with an impact velocity of 5.0 m/s using a hydraulic shock absorption apparatus or an air shock absorption apparatus, in accordance with embodiments.

FIG. **18**D shows angular acceleration data collected from impact testing shown in FIG. **18**A and FIG. **18**B with an impact velocity of 5.0 m/s using a hydraulic shock absorption apparatus or an air shock absorption apparatus, in accordance with embodiments.

FIG. **18**E shows linear acceleration data collected from impact testing shown in FIG. **18**A and FIG. **18**B with an impact velocity of 7.4 m/s using a hydraulic shock absorption apparatus or an air shock absorption apparatus, in accordance with embodiments.

FIG. **18**F show angular acceleration data collected from impact testing shown in FIG. **18**A and FIG. **18**B with an impact velocity of 7.4 m/s using a hydraulic shock absorption apparatus or an air shock absorption apparatus, in accordance with embodiments.

DETAILED DESCRIPTION

Provided herein are devices, systems, and methods for absorption of energy, for example, from a shock impact. In many cases, devices and systems disclosed herein are both collapsible (e.g. fully or nearly fully collapsible) and passively adaptable to different impact conditions. Devices and systems described herein comprise novel structural features and arrangements that result in ideal force profiles for energy absorption at a wide range of impact velocities while simultaneously offering compact designs requiring minimal spatial allowance. Accordingly, the devices and systems (and the methods of use thereof) disclosed herein are extremely versatile with respect to the types of energy absorption applications for which they can be used effectively.

In many cases, devices and systems disclosed herein can provide ideal energy absorption profiles for both low-speed impact events and high-speed impact events. In many cases, devices and systems disclosed herein can provide such advantages to energy absorption while simultaneously leveraging economic spatial designs disclosed herein to allow incorporation into existing hardware without significant modification of the augmented hardware. For example, one or more energy absorption devices disclosed herein can be incorporated into existing helmet designs, improving impact absorption performance without necessitating significant changes to the helmets in order to accommodate the inclusion of the absorption device(s). Furthermore, the modular design of various energy absorption devices disclosed herein allows for custom design of energy absorption systems for use in specific, and potentially specialized, applications. For example, one or more energy absorption devices disclosed herein can be used in shipping application, such as the shipment of large, fragile, and/or irregularly shaped items. In some cases, a system comprising one or more energy absorption devices disclosed herein may be suitable for industrial or manufacturing applications, for example, where the system can be used to absorb and/or dissipate impact forces on a heavy object (e.g. the chassis of a vehicle) wherein available space may be insufficient to employ a traditional rigid shock absorber.

In general, an energy absorption device **100** (e.g. an apparatus for absorbing energy) disclosed herein comprises a first chamber **120** (e.g. a pressure chamber) in fluid communication (e.g. bidirectional fluid communication) with a second chamber **110** (e.g. a refill chamber), for example, via one or more orifices **140** in a wall **121** of the first chamber **120**. In many cases, a second chamber **110** at least partially encloses an outer surface of a wall **121** of the first chamber **120**. In many cases, a wall **121** of a first chamber **120** is a reinforced wall (e.g. to provide resistance to deformation under loading). In many cases, a fluid (e.g. an incompressible fluid, such as liquid water) is disposed within the first chamber **120**, e.g. when the first chamber **120** is in an undeformed state. In some cases, a fluid is disposed within an interstitial volume **132** of an (e.g. undeformed) energy absorption device **100**. In some cases, a fluid disposed within an interstitial volume **132** of an (e.g. undeformed) energy absorption device **100** is a liquid (e.g. liquid water). In some cases (e.g. applications wherein an energy absorption device **100** is used in a portable device), the weight of the device is reduced by reducing the total interior volume **128** of the first chamber **120** and/or the interstitial volume **132** (e.g. in an undeformed state), for example, because the fluid contributes the majority of the overall weight of the device. Axial compression of the energy absorption device **100** (e.g. resulting from an external shock impact at a first end **102** compressing the energy absorption device or a portion thereof against a solid support **190**) can cause the incompressible fluid to be pressurized within the first chamber **120**, for example, through the deformation of the first chamber **120**. In some cases, a fluid within an energy absorption device **100** can be pre-pressurized (e.g. while no external forces are acting upon the device). In many cases, pre-pressurizing a fluid within an energy absorption device **100** pre-stretches (e.g. pre-tensions) a wall **111** of a second chamber, which can bias the fluid inward into an interior volume **128** of the first chamber. A fluid can be pre-pressurized to 0 to 10 kPa, 10 kPa to 20 kPa, 20 kPa to 30 kPa, 30 kPa to 40 kPa, 40 kPa to 50 kPa, 50 kPa to 60 kPa, 60 kPa to 68.9 kPa, 68.9 kPa to 80 kPa, 80 kPa to 90 kPa, 90 kPa to 100 kPa, or greater than 100 kPa. Pressurization of the incompressible fluid within an interior volume **128** of the first chamber **120** of the energy absorption device **100** (e.g. through partial or complete collapse of a wall **121** of the first chamber **120** during loading from an external force) can cause the incompressible fluid to flow through one or more orifices **140** in the wall **121** of the first chamber into an interstitial volume **132** (e.g. a reservoir space) disposed between an outer surface of the wall **121** of the first chamber and an inner surface of a wall **111** of the second chamber. In many cases, the first chamber **120** (e.g. or a wall **121** thereof) resists circumferential expansion. In many cases, flow of the incompressible fluid through the one or more orifices **140** into the interstitial volume **132** causes a wall **111** of the second chamber **110** (which can be coupled to the wall **121** of the first chamber, e.g. via a watertight seal) to deform (e.g. to expand or stretch). In some cases, flow of the incompressible fluid through the one or more orifices **140** into the interstitial volume **132** (which can receive the incompressible fluid in many cases) causes the wall **111** of the second chamber to expand, e.g. circumferentially outward, in a radial direction away from a longitudinal axis of the energy absorbing device **100**. In many cases, the deformation of the wall **111** of the second chamber functions to absorb and/or dissipate energy from the axial compression of the first chamber **120** (e.g. as imparted by the momentum of the incompressible fluid flowing into the interstitial volume **132**).

In many embodiments, the energy absorption device **100** can passively return the fluid from the interstitial volume to the interior volume **128** of the first chamber **120** (e.g. through the elasticity of the wall **111** of the second chamber recoiling and returning the interstitial volume back to its original geometry). In many cases, fluid use one or more orifices **140** or ports **131** to flow back from the interstitial volume **132** to an interior volume **128** of an energy absorption device.

Turning to FIG. **1**A, an energy absorption device **100** comprising first chamber **120** having a first wall **121** and a second chamber **110** having a second wall **111** is presented. The example presented in FIG. **1**A, which has a cylindrical shape, is one of many possible embodiments of an energy absorption device, each of which can have different advantages, e.g. for different applications. As discussed further herein, the shape, size, and/or constituent material properties of the first chamber wall **121**, the shape, size, and/or constituent material properties of the second chamber wall **111**, the shape, size, quantity, and/or arrangement of the one or more orifices **140**, the shape and/or size of the interior volume **128** of first chamber, and/or the shape and/or size of the interstitial volume **132** can affect the dynamics of shock impact absorption of an energy absorption device **100** or system and can be selected according to the disclosures herein to produce ideal energy absorption dynamics, for example, in applications such as manufacturing, the automotive industry, transportation, or protection of biological tissues (e.g. via personal protective equipment (PPE)).

A wall **121** of a first chamber **120** can be coupled to a wall **111** of a second chamber **110** at a wall coupling **180** (e.g. joint), for example as shown in FIG. **1**B. In many cases, a wall coupling **180** of an energy absorption device **100** is a watertight seal. In many cases, a watertight seal between a wall **121** of a first chamber **120** and a wall **111** of a second chamber **110** can allow the second chamber **110** of an energy absorption device **100** to be pressurized. A second chamber **110** can be pressurized by increasing the volume of fluid in the second chamber **110**, for example, by flowing a fluid from the interior **128** of a first chamber **120** through one or more orifice **140** into the interstitial space **132** (e.g. as a result of deformation to a first chamber **120** of the device). In many cases, a wall **111** of a second chamber **110** does not comprise an orifice **140**. A wall **111** (or portion thereof) of a second chamber **110** can be deformed, in many cases. For example, a wall **111** of a second chamber can comprise an elastic material (e.g. rubber, and the movement of a fluid from the interior volume **128** of the first chamber **120** to the interstitial space **132** can cause an elastic wall **111** to stretch. As described herein, pressurizing the second chamber **120** and/or deforming a wall **111** of the second chamber **120** can dissipate or absorb energy from an external force or pressure (e.g. an external impact force). In many cases, the interstitial space **132** is in bidirectional fluidic communication with the interior volume **128** of the first chamber **120** of the device **100** (e.g. via at least one orifice disposed through a wall **121** of the first chamber **120**). In some cases, the interstitial space **132** is in bidirectional fluidic communication with the interior volume **128** of a first chamber **120** and an interior volume **128** of a second first chamber **120**.

FIGS. **2**A-**2**E show an example of an energy absorption device **100** (e.g. a cylindrical energy absorption device **100**, for example, a cylindrical apparatus). FIGS. **2**C-**2**E show exploded views of the energy absorption device **100** shown in FIG. **2**A and FIG. **2**B. In many embodiments, a wall **121** of a first chamber **120** and a wall **111** of a second chamber **120** of an energy absorption device **100** are arranged concentrically around a longitudinal axis of the energy absorption device **100**. In many cases, the all or a portion of a wall **111** of a second chamber **120** is disposed at a greater radial distance from a longitudinal axis of an energy absorption device **100** than a wall **121** of a first chamber. Optionally, an energy absorption device **100** can comprise an interstitial material **130**. In many cases, an interstitial material **130** of an energy absorption device **100** is disposed concentrically with one or more wall (e.g. wall **111** and/or wall **121**) or a portion thereof. Typically, an interstitial material **130** is disposed between a wall **111** (e.g. an inner surface of wall **111**) or a portion thereof of a second chamber **110** and a wall **121** (e.g. an outer surface of wall **121**) or a portion thereof of a first chamber **120** of an energy absorption device **100**. In some cases, an interstitial material **130** can be disposed at a smaller radial distance from a longitudinal axis of the energy absorption device **100** than a wall **121** (e.g. a side wall **121**) or portion thereof of a first chamber.

In many cases, a wall **121** of a first chamber **120** (e.g. a pressure chamber) of an energy absorption device **100** is fabricated from a single piece of material. In many cases, a wall **111** of a second chamber **110** (e.g. a refill chamber) of an energy absorption device **100** is fabricated from a single piece of material. In some cases, a first chamber **120** of an energy absorption device **100** comprises a plurality of walls **121** (e.g. one or more side walls, a wall at a first (e.g. distal) end **102** of the device, and/or a wall at a second (e.g. proximal) end **104** of the device). In some cases, a second chamber **110** of an energy absorption device **100** comprises a plurality of walls **111** (e.g. one or more side walls, a wall at a first (e.g. distal) end **102** of the device, and/or a wall at a second (e.g. proximal) end **104** of the device). In many cases, a wall **111** (or plurality of walls **111**) of a second chamber **110** of an energy absorption device **100** surrounds or encloses at least a portion of a wall **121** of a first chamber **120** of the energy absorption device **100**.

A wall **111** of a second chamber **110** can be coupled to a wall **121** of a first chamber **120** in a variety of configurations, e.g. as described herein. In many cases, the geometrical relationship of the wall **121** of the first chamber **120** to the wall **111** of the second chamber can affect the energy absorption properties of the energy absorption device **100**, e.g. by determining the shape of the second chamber **110** and the interstitial volume **132**, which can be formed by an inner surface of a wall **111** of the second chamber **110** and a portion of an outer surface of a wall **121** of the first chamber **120**. In many cases, a wall **111** (or plurality of walls **111**) of a second chamber **110** of an energy absorption device **100** surrounds or encloses at least a portion of a wall **121** of a first chamber **120** of the energy absorption device **100**. In some cases, a wall **111** (or plurality of walls **111**) of a second chamber **110** of an energy absorption device **100** surrounds or encloses the entirety of the first chamber **120** (e.g. and the entirety of the wall(s) **121** of the first chamber). In some cases, a wall **111** of a second chamber **110** of an energy absorption device is coupled to a wall **121** of a first chamber **120** of the energy absorption device (e.g. at a wall coupling **180**, for example, wherein the wall coupling is a watertight seal).

FIG. **3**A and FIG. **3**B show schematics of undeformed and deformed energy absorption device, respectively, and FIG. **3**C and FIG. **3**D show photographs of fabricated energy absorption device **100** with no loading (FIG. **3**C) and under axial compression loading (FIG. **3**D). In many cases, the wall **121** of the first chamber is collapsible. In many cases, a first chamber **120** of an energy absorption device **100** is axially collapsible. The wall **121** of the first chamber can be resilient. In many cases, the wall **121** of the first chamber is at least partially resistant to deformation (e.g. compression or collapse) in an axial direction. In some cases, the force exerted by a wall **121** of a first chamber **120** during deformation can increase as the wall becomes progressively more deformed (e.g. more compressed or collapsed). As exemplified in FIGS. **3**A-**3**D, one or more walls **121** of the first chamber (and/or one or more walls **111** of the second chamber) can be oriented in a direction parallel to or substantially parallel to a direction of an expected external force, e.g. to provide resistance to the external force during its application to the device **100**. For instance, one or more walls (e.g. wall **121** and/or wall **111**) can be oriented parallel to or substantially parallel to a longitudinal axis **106** of an energy absorption device **100** when an external force is expected to compress the device in an axial direction, for example, to provide resistance to the external force during its application to the device. In many cases, a first chamber **120** of an energy absorption device **100** is axially collapsible (e.g. parallel to or substantially parallel to a longitudinal axis **106** of the device). In many cases, a first chamber **120** of an energy absorption device **100** is elongated in an axial direction (e.g. parallel to or substantially parallel to a longitudinal axis **106** of the device), for example, to facilitate axially collapse of the device under loading. It will be appreciated that selection of one or more out of numerous possible geometries of a wall (e.g. wall **121** or wall **111**) of an energy absorption device **100** can be utilized (e.g. in combination with the material properties of the wall material) can aid in achieving a desired compression or collapse profile over time during application of an external force.

FIGS. **10I-10J** show examples of geometries of wall **121** of the first chamber and/or wall **111** of the second chamber (e.g. in an undeformed state or in a deformed state) that can be utilized in the design of an energy absorption device **100**. Among the wall geometries useful in the design of an energy absorption device are cylindrical, cuboid, rectangular parallelepiped, hemispherical, spheroid, ellipsoid, oblate spheroid, prolate spheroid, ovoid, toroidal, tetrahedral, octahedral, dodecahedral, icosahedral, hyperboloid, conical, oblique conical, and truncated conical. In some cases, a wall (e.g. wall **121** or wall **111**) or chamber (e.g. first chamber **120** or second chamber **110**) can comprise a sagittal or coronal (e.g. through a longitudinal axis **106** of the device) cross-section geometry of a square, a rectangle, a rhombus, a trapezoid, a pentagon, a hexagon, an octagon, or a polygon having more than 9 sides (e.g. as shown in FIG. **10**J). In some cases, a wall (e.g. wall **121** or wall **111**) or chamber (e.g. first chamber **120** or second chamber **110**) can comprise a transverse (e.g. perpendicular to a longitudinal axis **106** of the device) cross-section geometry of a square, a rectangle, a rhombus, a circle, a semicircle, an oval, an ellipse, a triangle (e.g. a right triangle, an isosceles triangle, a scalene triangle, or an equilateral triangle), a trapezoid, a pentagon, a hexagon, an octagon, or a polygon having more than 9 sides (e.g. as shown in FIGS. **10**B, **10**D, **10**F, **10**H, and **10**J).

In some cases, a first chamber **120** and/or a second chamber **110** of an energy absorption device **100** comprises no more than one side. In some cases, a first chamber **120** and/or a second chamber **110** of an energy absorption device **100** comprises a plurality of sides. In some cases, a first chamber **120** and/or a second chamber **110** of an energy absorption device **100** comprises 2, 3, 4, 5, 6, 7, 8, 9, 10, from 10 to 15, from 15 to 30, from 30 to 50, or more than 50 sides.

In some cases, a first chamber **120** and/or a second chamber **110** of an energy absorption device **100** comprises no more than one wall. In some cases, a first chamber **120** and/or a second chamber **110** of an energy absorption device **100** comprises a plurality of walls. In some cases, a first chamber **120** and/or a second chamber **110** comprises an end wall. In some cases, a first chamber **120** and/or a second chamber **110** comprises an end wall at a distal end **102** of an energy absorption device **100**. In some cases, a first chamber **120** and/or a second chamber **110** comprises an end wall at a proximal end **104** of an energy absorption device **100**. In some cases, a first chamber **120** and/or a second chamber **110** comprises a plurality of end walls. In some cases, a first chamber **120** and/or a second chamber **110** comprises a first end wall at a distal end **102** and a second end wall at a proximal end **104** of an energy absorption device **100**. In some cases, an end wall of an energy absorption device can comprise an end cap. In some cases, an end cap comprises a reinforced wall (e.g. at a proximal end **104** or a distal end **102** of an energy absorption device **100**). In some cases, a first chamber **120** and/or a second chamber **110** of an energy absorption device **100** comprises a side wall. In some cases, a first chamber **120** and/or a second chamber **110** of an energy absorption device **100** comprises a plurality of side walls. In some cases, a first chamber **120** and/or a second chamber **110** of an energy absorption device **100** comprises 2, 3, 4, 5, 6, 7, 8, 9, 10, from 10 to 15, from 15 to 30, from 30 to 50, or more than 50 side walls.

In some cases, the maximum width **114** of an energy absorption device **100** (or a portion thereof, such as a first chamber **120** of an energy absorption device) in an undeformed state is the same or substantially the same as the maximum width **152** of the energy absorption device in a deformed state (e.g. after deformation). In some cases, the maximum width **114** of an energy absorption device **100** (or a portion thereof, such as a first chamber **120** of an energy absorption device) in an undeformed state is less than the maximum width **152** of the energy absorption device in a deformed state. In some cases, the maximum width of a distal end of an energy absorption device **100** (or a portion thereof, such as a first chamber **120** of an energy absorption device) in an undeformed state is less than the maximum width of the distal end of the energy absorption device (or a portion thereof) in a deformed state. In some cases, the maximum width of a distal end of an energy absorption device **100** (or a portion thereof, such as a first chamber **120** of an energy absorption device) in an undeformed state is less than the maximum width of the distal end of the energy absorption device (or a portion thereof) in a deformed state, for example while the maximum width of a proximal end of the energy absorption device in the undeformed state is the same as or is substantially the same as the maximum width of the proximal end of the energy absorption device in the deformed state. In some cases, the maximum width of a distal end of an energy absorption device **100** (or a portion thereof, such as a first chamber **120** of an energy absorption device) in an undeformed state is the same as or substantially the same as the maximum width of the distal end of the energy absorption device (or a portion thereof) in a deformed state.

In some cases, a first chamber **120** and/or a second chamber **110** of an energy absorption device can comprise a waist region **153**. In some cases, a waist region **153** of a first chamber **120** and/or a second chamber **110** has a smaller maximal width **154** in an undeformed state than the maximum width **114** of the first chamber **120** or second chamber **110** in the undeformed state. In some cases, a waist region **153** of a first chamber **120** has a smaller maximal width in a deformed state **156** than the maximal width **152** of the first chamber **120** in the deformed state.

A wall **121** of the first chamber **120** can be resistant to deformation (e.g. multiple axis deformation, bending, shearing, torsional deformation, compression, or collapse) in a direction perpendicular to a longitudinal axis **106** of the energy absorption device **100**. For instance, a wall **121** of the first chamber can be at least partially resistant to shearing deformation. In many cases, the resilience of a wall **121** of a first chamber can increase the resistance to bending or shearing deformation of the wall **121**. In some cases, the stiffness of an interstitial material **130** can be selected to resist or allow bending and/or shearing deformation of a wall **121** of a first chamber. In some cases, an impact stroke of an energy absorption device **100** can be at an angle of 0 to 90 degrees, 0 to 60 degrees, 0 to 45 degrees, or 0 to 30 degrees of an axis of an impact. In some cases, an impact stroke of an energy absorption device **100** can be at an angle of 0 to 90 degrees, 0 to 60 degrees, 0 to 45 degrees, or 0 to 30 degrees of a longitudinal axis of the device.

In some cases, an energy absorption device deforms in an axial direction (e.g. axial compression). In some cases, an energy absorption device deforms in a lateral or radial direction (e.g. lateral shearing or buckling with a lateral deformation aspect). In some cases, a structural aspect of an energy absorption device **100** is designed to aid in controlling deformation of the device. For example, a portion of an energy absorption device **100** (e.g. a wall **121** of a first chamber **120**) can comprise a waist **153** (e.g. as shown in FIG. **10**C, which can promote buckling of a wall (e.g. wall **121**) of the device.

It will be appreciated that selection of a geometry for a wall (wall **121** or wall **111**) or chamber (e.g. first chamber **120** or second chamber **110**) of an energy absorption device can affect the force the device exerts against an external force and/or the rate at which the device (or a portion thereof) deforms. Deformation (e.g. axial collapse) of an energy absorption device **100** under loading from an external force can change the geometry (e.g. area) of a portion of the energy absorption device in contact (e.g. contact area, A_c) with an object (e.g. mass, m) exerting the external force (e.g. at a velocity v_o) on the device (e.g. as shown in FIG. **4**A, FIG. **4**B, FIG. **4**C, and FIG. **4**D), which can change the amount of force the energy absorption device exerts on the object over time. For example, axial compression of a first chamber **120** of an energy absorption device **100** can cause contact area A_c to increase as displacement x in a proximal direction increases (e.g. and as fluid within the first chamber flows (Q) out of the first chamber via one or more orifice **140**). An example of loading of an energy absorption device **100** (e.g. damper) designed to change the area of a portion of a wall **121** of a first chamber in contact with an object exerting an external force (e.g. a variable contact area apparatus, VCAA) is shown in FIGS. **15**A and **15**B. Various specific force levels can be achieved by designing the VCAA to have specific initial (e.g. undeformed) first chamber heights **112**, initial (e.g. undeformed) proximal end widths **116**, and initial (e.g. undeformed) distal end widths **114**, e.g. as shown in FIGS. **5**A-**5**D.

An energy absorption device **100** can be coupled to a solid support **190** (e.g. as in FIG. **17**A-**17**E and FIG. **18**A-**18**B). In some cases, an energy absorption device **100** is permanently coupled to a solid support **190**. In some cases, an energy absorption device **100** is removably coupled (e.g. detachably coupled) to a solid support **190**. In many cases, an energy absorption device **100** is coupled to a solid support **190** at a proximal end **104** of a first chamber **120**. In some cases, an energy absorption device **100** is coupled to a solid support **190** at a proximal end **104** of a second chamber **110**. In some cases, an elastically compressible material **192** can be coupled to the solid support **190** (e.g. adjacent to an energy absorption device **100**). In some cases, an elastically compressible material **192** can be coupled to a solid support **190** adjacent to an energy absorption device **100**. In some cases, an elastically compressible material **192** can be coupled to an inner surface of a wall **121** of a first chamber **120** (e.g. at a proximal end of the first chamber **120**), for example, as shown in FIG. **9**B.

Orifices

An energy absorption device **100** can comprise one or more orifices **140**. In various embodiments, an orifice can be a channel through a structure (e.g. a wall **121** of first chamber **120**) of an energy absorption device **100**. In many cases, an orifice of an energy absorption device **100** places a first chamber **120** in bidirectional fluidic communication with a second chamber **110** of the device, e.g. allowing bidirectional fluid flow between an interior volume **128** of a first chamber **120** and an interstitial volume **132** (e.g. wherein the interstitial space is disposed between an outer surface of a wall **121** of a first chamber **120** and an inner surface of a wall **111** of a second chamber). For example, an orifice can serve as a channel or path for fluid contained within the interior **128** of a first chamber **120** of an energy absorption device **100** to travel (e.g. flow) into an interstitial volume **132** of the device (e.g. during deformation of the first chamber **120** by an external force or pressure). In many cases, the orifice can also serve as a channel or path for fluid contained within an interstitial volume **132** to travel (e.g. flow) into the interior volume **128** of a first chamber **120** (e.g. as the walls of the first chamber return to their undeformed state after removal of the external force or pressure).

In some cases, an orifice **140** can comprise a channel through a side wall of a first chamber **120**. In some cases, an orifice **140** can comprise a channel through a wall **121** at a proximal end **104** or a distal end **102** of a first chamber **120** (e.g. as shown in FIG. **7**C, FIG. **9**E.

The energy absorption properties of an energy absorption device **100** can be affected by the quantity, size, and/or arrangement of one or more orifices **140** disposed in wall **121** of the first chamber **120**. In some cases, an energy absorption device **100** comprises no more than one orifice **140**. In some cases, an energy absorption device **100** comprises a plurality of orifices **140**.

In some embodiments, a wall **121** of a first chamber **120** can comprise 1 orifice to 50 orifices.

In some embodiments, a wall **121** of a first chamber **120** can comprise 1 orifice to 2 orifices, 1 orifice to 3 orifices, 1 orifice to 4 orifices, 1 orifice to 5 orifices, 1 orifice to 6 orifices, 1 orifice to 7 orifices, 1 orifice to 8 orifices, 1 orifice to 9 orifices, 1 orifice to 10 orifices, 1 orifice to 20 orifices, 1 orifice to 50 orifices, 2 orifices to 3 orifices, 2 orifices to 4 orifices, 2 orifices to 5 orifices, 2 orifices to 6 orifices, 2 orifices to 7 orifices, 2 orifices to 8 orifices, 2 orifices to 9 orifices, 2 orifices to 10 orifices, 2 orifices to 20 orifices, 2 orifices to 50 orifices, 3 orifices to 4 orifices, 3 orifices to 5 orifices, 3 orifices to 6 orifices, 3 orifices to 7 orifices, 3 orifices to 8 orifices, 3 orifices to 9 orifices, 3 orifices to 10 orifices, 3 orifices to 20 orifices, 3 orifices to 50 orifices, 4 orifices to 5 orifices, 4 orifices to 6 orifices, 4 orifices to 7 orifices, 4 orifices to 8 orifices, 4 orifices to 9 orifices, 4 orifices to 10 orifices, 4 orifices to 20 orifices, 4 orifices to 50 orifices, 5 orifices to 6 orifices, 5 orifices to 7 orifices, 5 orifices to 8 orifices, 5 orifices to 9 orifices, 5 orifices to 10 orifices, 5 orifices to 20 orifices, 5 orifices to 50 orifices, 6 orifices to 7 orifices, 6 orifices to 8 orifices, 6 orifices to 9 orifices, 6 orifices to 10 orifices, 6 orifices to 20 orifices, 6 orifices to 50 orifices, 7 orifices to 8 orifices, 7 orifices to 9 orifices, 7 orifices to 10 orifices, 7 orifices to 20 orifices, 7 orifices to 50 orifices, 8 orifices to 9 orifices, 8 orifices to 10 orifices, 8 orifices to 20 orifices, 8 orifices to 50 orifices, 9 orifices to 10 orifices, 9 orifices to 20 orifices, 9 orifices to 50 orifices, 10 orifices to 20 orifices, 10 orifices to 50 orifices, or 20 orifices to 50 orifices.

In some embodiments, a wall **121** of a first chamber **120** can comprise 1 orifice, 2 orifices, 3 orifices, 4 orifices, 5 orifices, 6 orifices, 7 orifices, 8 orifices, 9 orifices, 10 orifices, 20 orifices, or 50 orifices.

In some embodiments, a wall **121** of a first chamber **120** can comprise at least 1 orifice, 2 orifices, 3 orifices, 4 orifices, 5 orifices, 6 orifices, 7 orifices, 8 orifices, 9 orifices, 10 orifices, or 20 orifices.

In some embodiments, a wall **121** of a first chamber **120** can comprise at most 2 orifices, 3 orifices, 4 orifices, 5 orifices, 6 orifices, 7 orifices, 8 orifices, 9 orifices, 10 orifices, 20 orifices, or 50 orifices.

In some embodiments, the (e.g. maximum) axial height **142** of an orifice can be 0.1 mm to 25 mm.

In some embodiments, the (e.g. maximum) axial height **142** of an orifice can be 0.1 mm to 1 mm, 0.1 mm to 2 mm, 0.1 mm to 3 mm, 0.1 mm to 4 mm, 0.1 mm to 5 mm, 0.1 mm to 7.5 mm, 0.1 mm to 10 mm, 0.1 mm to 12.5 mm, 0.1 mm to 15 mm, 0.1 mm to 20 mm, 0.1 mm to 25 mm, 1 mm to 2 mm, 1 mm to 3 mm, 1 mm to 4 mm, 1 mm to 5 mm, 1 mm to 7.5 mm, 1 mm to 10 mm, 1 mm to 12.5 mm, 1 mm to 15 mm, 1 mm to 20 mm, 1 mm to 25 mm, 2 mm to 3 mm, 2 mm to 4 mm, 2 mm to 5 mm, 2 mm to 7.5 mm, 2 mm to 10 mm, 2 mm to 12.5 mm, 2 mm to 15 mm, 2 mm to 20 mm, 2 mm to 25 mm, 3 mm to 4 mm, 3 mm to 5 mm, 3 mm to 7.5 mm, 3 mm to 10 mm, 3 mm to 12.5 mm, 3 mm to 15 mm, 3 mm to 20 mm, 3 mm to 25 mm, 4 mm to 5 mm, 4 mm to 7.5 mm, 4 mm to 10 mm, 4 mm to 12.5 mm, 4 mm to 15 mm, 4 mm to 20 mm, 4 mm to 25 mm, 5 mm to 7.5 mm, 5 mm to 10 mm, 5 mm to 12.5 mm, 5 mm to 15 mm, 5 mm to 20 mm, 5 mm to 25 mm, 7.5 mm to 10 mm, 7.5 mm to 12.5 mm, 7.5 mm to 15 mm, 7.5 mm to 20 mm, 7.5 mm to 25 mm, 10 mm to 12.5 mm, 10 mm to 15 mm, 10 mm to 20 mm, 10 mm to 25 mm, 12.5 mm to 15 mm, 12.5 mm to 20 mm, 12.5 mm to 25 mm, 15 mm to 20 mm, 15 mm to 25 mm, or 20 mm to 25 mm.

In some embodiments, the (e.g. maximum) axial height **142** of an orifice can be 0.1 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 7.5 mm, 10 mm, 12.5 mm, 15 mm, 20 mm, or 25 mm.

In some embodiments, the (e.g. maximum) axial height **142** of an orifice can be at least 0.1 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 7.5 mm, 10 mm, 12.5 mm, 15 mm, 20 mm, or 25 mm.

In some embodiments, the (e.g. maximum) axial height **142** of an orifice can be at most 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 7.5 mm, 10 mm, 12.5 mm, 15 mm, 20 mm, or 25 mm.

In some embodiments, the (e.g. maximum) width **144** of an orifice can be 0.1 mm to 25 mm.

In some embodiments, the (e.g. maximum) width **144** of an orifice can be 0.1 mm to 1 mm, 0.1 mm to 2 mm, 0.1 mm to 3 mm, 0.1 mm to 4 mm, 0.1 mm to 5 mm, 0.1 mm to 7.5 mm, 0.1 mm to 10 mm, 0.1 mm to 12.5 mm, 0.1 mm to 15 mm, 0.1 mm to 20 mm, 0.1 mm to 25 mm, 1 mm to 2 mm, 1 mm to 3 mm, 1 mm to 4 mm, 1 mm to 5 mm, 1 mm to 7.5 mm, 1 mm to 10 mm, 1 mm to 12.5 mm, 1 mm to 15 mm, 1 mm to 20 mm, 1 mm to 25 mm, 2 mm to 3 mm, 2 mm to 4 mm, 2 mm to 5 mm, 2 mm to 7.5 mm, 2 mm to 10 mm, 2 mm to 12.5 mm, 2 mm to 15 mm, 2 mm to 20 mm, 2 mm to 25 mm, 3 mm to 4 mm, 3 mm to 5 mm, 3 mm to 7.5 mm, 3 mm to 10 mm, 3 mm to 12.5 mm, 3 mm to 15 mm, 3 mm to 20 mm, 3 mm to 25 mm, 4 mm to 5 mm, 4 mm to 7.5 mm, 4 mm to 10 mm, 4 mm to 12.5 mm, 4 mm to 15 mm, 4 mm to 20 mm, 4 mm to 25 mm, 5 mm to 7.5 mm, 5 mm to 10 mm, 5 mm to 12.5 mm, 5 mm to 15 mm, 5 mm to 20 mm, 5 mm to 25 mm, 7.5 mm to 10 mm, 7.5 mm to 12.5 mm, 7.5 mm to 15 mm, 7.5 mm to 20 mm, 7.5 mm to 25 mm, 9 mm to 25 mm, 10 mm to 12.5 mm, 10 mm to 15 mm, 10 mm to 20 mm, 10 mm to 25 mm, 12.5 mm to 15 mm, 12.5 mm to 20 mm, 12.5 mm to 25 mm, 15 mm to 17 mm, 15 mm to 18 mm, 15 mm to 20 mm, 15 mm to 25 mm, or 20 mm to 25 mm.

In some embodiments, the (e.g. maximum) width **144** of an orifice can be 0.1 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 7.5 mm, 10 mm, 12.5 mm, 15 mm, 16.5 mm, 18 mm, 20 mm, or 25 mm.

In some embodiments, the (e.g. maximum) width **144** of an orifice can be at least 0.1 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 7.5 mm, 9 mm, 10 mm, 12.5 mm, 15 mm, 18 mm, 20 mm, or 25 mm.

In some embodiments, the (e.g. maximum) width **144** of an orifice can be at most 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 7.5 mm, 9 mm, 10 mm, 12.5 mm, 15 mm, 18 mm, 20 mm, or 25 mm.

When finite element modeling was used to simulate force exerted by a cylindrical energy absorber over time while being subjected to an external axial compressive impact, it was found that 9 mm diameter orifices produced a flatter force curve than identical devices having orifices of diameter 8.0 mm or 8.5 mm (see FIG. **10**B). This data indicates that, in some embodiments, a larger orifice diameter is beneficial to limiting variation in force over time (e.g. and reducing the likelihood of potentially damaging accelerations). These results were supported by subsequent experiments (see e.g. FIG. **11**A and FIG. **11**B). In some embodiments, optimal ranges of orifice diameter are below 24 mm or 25 mm (e.g. from 9 mm to 25 mm, from 9 mm to 24 mm, from 15 mm to 24 mm, or from 15 mm to 25 mm), including devices with orifice diameters of 18 mm.

In some embodiments, the cross-sectional area of an orifice can be 0.5 mm^2 to 1,000 mm^2.

In some embodiments, the cross-sectional area of an orifice can be 0.5 mm^2 to 1 mm^2, 0.5 mm^2 to 5 mm^2, 0.5 mm^2 to 15 mm^2, 0.5 mm^2 to 25 mm^2, 0.5 mm^2 to 50 mm^2, 0.5 mm^2 to 75 mm^2, 0.5 mm^2 to 100 mm^2, 0.5 mm^2 to 250 mm^2, 0.5 mm^2 to 500 mm^2, 0.5 mm^2 to 750 mm^2, 0.5 mm^2 to 1,000 mm^2, 1 mm^2 to 5 mm^2, 1 mm^2 to 15 mm^2, 1 mm^2 to 25 mm^2, 1 mm^2 to 50 mm^2, 1 mm^2 to 75 mm^2, 1 mm^2 to 100 mm^2, 1 mm^2 to 250 mm^2, 1 mm^2 to 500 mm^2, 1 mm^2 to 750 mm^2, 1 mm^2 to 1,000 mm^2, 5 mm^2 to 15 mm^2, 5 mm^2 to 25 mm^2, 5 mm^2 to 50 mm^2, 5 mm^2 to 75 mm^2, 5 mm^2 to 100 mm^2, 5 mm^2 to 250 mm^2, 5 mm^2 to 500 mm^2, 5 mm^2 to 750 mm^2, 5 mm^2 to 1,000 mm^2, 15 mm^2 to 25 mm^2, 15 mm^2 to 50 mm^2, 15 mm^2 to 75 mm^2, 15 mm^2 to 100 mm^2, 15 mm^2 to 250 mm^2, 15 mm^2 to 500 mm^2, 15 mm^2 to 750 mm^2, 15 mm^2 to 1,000 mm^2, 25 mm^2 to 50 mm^2, 25 mm^2 to 75 mm^2, 25 mm^2 to 100 mm^2, 25 mm^2 to 250 mm^2, 25 mm^2 to 500 mm^2, 25 mm^2 to 750 mm^2, 25 mm^2 to 1,000 mm^2, 50 mm^2 to 75 mm^2, 50 mm^2 to 100 mm^2, 50 mm^2 to 250 mm^2, 50 mm^2 to 500 mm^2, 50 mm^2 to 750 mm^2, 50 mm^2 to 1,000 mm^2, 75 mm^2 to 100 mm^2, 75 mm^2 to 250 mm^2, 75 mm^2 to 500 mm^2, 75 mm^2 to 750 mm^2, 75 mm^2 to 1,000 mm^2, 100 mm^2 to 250 mm^2, 100 mm^2 to 500 mm^2, 100 mm^2 to 750 mm^2, 100 mm^2 to 1,000 mm^2, 250 mm^2 to 500 mm^2, 250 mm^2 to 750 mm^2, 250 mm^2 to 1,000 mm^2, 500 mm^2 to 750 mm^2, 500 mm^2 to 1,000 mm^2, or 750 mm^2 to 1,000 mm^2.

In some embodiments, the cross-sectional area of an orifice can be 0.5 mm^2, 1 mm^2, 5 mm^2, 15 mm^2, 25 mm^2, 50 mm^2, 75 mm^2, 100 mm^2, 250 mm^2, 500 mm^2, 750 mm^2, or 1,000 mm^2.

In some embodiments, the cross-sectional area of an orifice can be at least 0.5 mm^2, 1 mm^2, 5 mm^2, 15 mm^2, 25 mm^2, 50 mm^2, 75 mm^2, 100 mm^2, 250 mm^2, 500 mm^2, 750 mm^2, 1,000 mm^2.

In some embodiments, the cross-sectional area of an orifice can be at most 1 mm^2, 5 mm^2, 15 mm^2, 25 mm^2, 50 mm^2, 75 mm^2, 100 mm^2, 250 mm^2, 500 mm^2, 750 mm^2, or 1,000 mm^2.

In some cases, an orifice **140** is round. For example, an orifice **140** can be circular in shape. In some cases, an orifice **140** is square or rectangular in shape. In some cases, an orifice **140** can be an arbitrary shape. For example, an orifice **140** can be shaped as an oval, an ellipse, a triangle, or another polygon.

In some cases, a wall **121** of a first chamber **120** of an energy absorption device **100** does not comprise any orifices, for example, wherein the wall **121** is permeable to a fluid disposed within the device. In some cases, a wall **121** of a first chamber **120** of an energy absorption device **100** does not comprise any orifices and the device does not comprise a second chamber **110**. For instance, an energy absorption device **100** that does not comprise a second chamber **110** can be a (e.g. single-use) device engineered (e.g. through the selection of an interstitial material **130** or material for wall **121**) to plastically deform or rupture at a desired fluid pressure within the interior volume **128** of the first chamber **120**. In some cases, a wall **121** and/or interstitial material **130** of an energy absorption device **100** comprising a first chamber **120** and a second chamber **110** does not comprise any orifices **140**. In some cases, a wall **121** can be engineered (e.g. through the selection of an interstitial material **130** or material for wall **121** or the inclusion of one or more thinned portions of the wall **121** or interstitial material **130**) to plastically deform or rupture into an interstitial volume **132** of the energy absorption device **100**, e.g. at a desired fluid pressure within the interior volume **128** of the first chamber **120**. For example, a wall **121** can comprise one or more first portions having a narrower thickness than the one or more second portions of wall **121**, wherein the thickness of the one or more first portions is selected to allow the one or more first portions (or one or more portions thereof) to rupture when a selected pressure is applied to the wall **121** (e.g. via pressurization of a fluid disposed within the first chamber **120**, for example, during deformation of the first chamber **120**). In some cases, an energy absorption device **100** comprising such portions of narrow thickness, decreased ultimate strength, and/or decreased yield strength can be used as a force sensor or pressure sensor (for example, wherein the deformation of the wall **121** or presence of the fluid in the interstitial volume **132**, e.g. due to rupture of the wall at the one or more first portions, indicates that a specified pressure or force has been exceeded). In some cases, a wall **111** of a second chamber can be optically translucent or transparent to facilitate observation of the presence of a fluid in the interstitial volume.

Interstitial Material

An interstitial material **130** (e.g. an interstitial membrane) can be disposed within the interstitial volume **132** of the energy absorption device **100**. In some cases, an interstitial material **130** can be disposed within the interior volume **128** of the first chamber **120** of the energy absorption device **100**. An interstitial material **130** can be disposed (e.g. concentrically) around at least a portion of a first chamber **120** of an energy absorption device (e.g. as shown in FIG. **1**B, FIG. **2**C, FIG. **2**D, and FIG. **2**E), which can result in increased resistance to a compressive force applied to an end (e.g. a distal end **102**) of the energy absorption device **100**.

The interstitial material **130** can provide structure to the energy absorption device **100**, for instance when the energy absorption device **100** is undeformed or not subjected to an external compressive force. For example, an interstitial material **130** of an energy absorption device **100** can provide an energy absorption device **100** with mechanical stiffness in one or more directions. In some cases, a material of a wall **121** of a first chamber **120** (and/or a wall **111** of a second chamber **110**) can be relatively soft, in some embodiments, to facilitate deformation (e.g. collapse) under loading conditions. In some cases, an interstitial material **130** can aid in maintaining the shape of the energy absorption device **100**, e.g. in the absence of an external force being applied to the device. A wall (e.g. of a first chamber **120**) of an energy absorption device **100** can comprise an interstitial material **130**.

In some cases, an interstitial material **130** comprises a membrane (e.g. a continuous sheet). In some cases, an interstitial material **130** comprises a mesh. For example, an interstitial material can be a continuous material comprising a plurality of openings disposed therethrough. In some cases, an interstitial material comprises a woven or knit material, e.g. having an open (e.g. web-like) weave. In some cases, an interstitial material **130** is a high-strength material (e.g. a high-strength fabric). In some cases, an interstitial material comprising a high-strength fabric comprises polytetrafluoroethylene (PTFE). In some cases, an interstitial material **130** comprises nickel titanium (e.g. nitinol). In some cases, an interstitial material comprises polyethylene (e.g. ultra-high molecular weight polyethylene (UHMWPE)). In some cases, an interstitial material **130** has a (e.g. tensile) yield strength of 10-1000 MPa, 100 MPa to 750 MPa, 200 MPa to 750 MPa, 750 MPa, to 1,000 MPa, 200 MPa to 400 MPa, 250 MPa to 500 MPa, or 400 MPa to 500 MPa. In some cases, an interstitial material **130** has a (e.g. tensile) ultimate strength of 10-1000 MPa, 100 MPa to 750 MPa, 200 MPa to 750 MPa, 750 MPa, to 1,000 MPa, 200 MPa to 400 MPa, 250 MPa to 500 MPa, or 400 MPa to 500 MPa.

In some cases, the physical properties (e.g. material strength, stiffness, and/or resilience) and/or geometry of an interstitial material **130** can affect the rate at which an energy absorption device **100** deforms under loading (e.g. during axial compression resulting, for example, from a shock impact). The permeability of an interstitial material **130** can affect the rate at which a second chamber **110** (or wall **111** of a second chamber) is deformed (e.g. by a fluid pressing against or flowing against a wall **111** of the second chamber after exiting an orifice **140** of a first chamber **120**). For example, a fluid exiting a first chamber **120** of an energy absorption chamber **100** via one or more orifices **140** can flow against interstitial material **130** prior to pressing against a wall **111** of the second chamber). In some cases, the interstitial material **130** can baffle or slow the flow of water against a wall **111** of a second chamber **110** of the energy absorption device **100**.

In some cases, the interstitial material **130** is permeable to a fluid (e.g. an incompressible fluid disposed within a chamber of the energy absorption device **100**). In some cases, a portion of the interstitial material **130** comprises a material that is impermeable to a fluid (e.g. an incompressible fluid disposed within a chamber of the energy absorption device **100**). In some cases, an interstitial material comprises one or more portions that are permeable to a fluid and one or more portions that are impermeable to a fluid. An interstitial material **130** or portion thereof can comprise a mesh. In some cases, a portion of an interstitial material **130** that comprises a mesh is permeable to a fluid. In some cases, the size of the gaps in the mesh can affect the efficiency of force transmission from a pressurized fluid in energy absorption device **100** to a wall **111** of a second chamber. For instance, an interstitial material **130** comprising a tight mesh (e.g. having smaller gaps in the mesh) can be more resistant to fluid flow through the mesh, which can decrease the velocity with which the fluid enters into or moves through the interstitial volume **132** (e.g. the reservoir space). Decreasing the velocity with which the fluid passes through the interstitial material **130** and/or the velocity with which the fluid enters into or moves through the interstitial volume **132** can increase the stiffness of the energy absorption device **100** and/or reduce the deformation of the wall **111** of the second chamber. Increasing the size of the mesh holes can permit fluid to flow through the interstitial material more easily and can result in a more compliant energy absorption device **100**. In some cases, an energy absorption device **100** comprising an interstitial material **130** (e.g. an interstitial material comprising a portion permeable to a fluid) does not comprise an orifice in a wall **121** of a first chamber **120** of the device.

In some cases, an interstitial material **130** is coupled to one or more additional structure (e.g. a wall **121** of a first chamber or a wall **111** of a second chamber) of an energy absorption device **100**. In many cases, an interstitial material **130** is not directly coupled to any other structure of an energy absorption device **100**. For example, an interstitial material **130** can be sandwiched between a wall **121** of a first chamber and a wall **111** of a second chamber of an energy absorption device **100** (e.g. disposed between, and optionally in contact with, wall **121** and wall **111**) without being directly joined to either wall **121** or wall **111**.

In some cases, an interstitial material **130** is (e.g. mechanically) isotropic or substantially isotropic (e.g. with respect to force transmission and/or deformation). For example, an interstitial material can comprise a continuous material capable of transmitting forces evenly in multiple directions (e.g. in three independent coordinate planes or in all directions within a two-dimensional plane). An interstitial material **130** can comprise a sheet, a membrane, or a layer (e.g. a layer of a wall **121**). In some cases, an isotropic interstitial material **130** comprises a composite material (e.g. a plastic composite or rubber composite). In some cases, an isotropic interstitial material comprises a layered weave (e.g. wherein individual layers of the material can be anisotropic but the orientation of the weaves (e.g. at an angle of 30 to 60 degrees, 60 to 90 degrees, or 90 degrees) relative to one or more additional layers of the weave results in a substantially isotropic interstitial material). In some cases, an interstitial material **130** is (e.g. mechanically) anisotropic (e.g. with respect to force transmission and/or deformation). For example, an interstitial material **130** may transmit stress or experience strain differentially depending on the direction of the stress or strain, e.g. wherein the interstitial material comprises threads, weaves, bands, or the like with anisotropic stress or strain characteristics.

Chamber Shapes and Dimensions

A first chamber **120** of an energy absorption device **100** can comprise various shapes. In many cases, an energy absorption device **100** (or chamber or wall thereof) is symmetrical (e.g. rotationally symmetrical or radially symmetrical) with respect to a longitudinal axis **106** of the device. In some cases, symmetry along a longitudinal axis promotes equal distribution of forces and pressures within an energy absorption device (e.g. when subjected to axial compression), which can reduce localized increases in force or pressure at one or more points on a wall (e.g. wall **111**, wall **121**) or coupling **180**, reducing the likelihood of fatigue or failure of the device's structural components at the one or more points.

In some embodiments, the (e.g. axial) height **122** of an undeformed first chamber can be 5 mm to 1,000 mm.

In some embodiments, the (e.g. axial) height **122** of an undeformed first chamber can be 5 mm to 10 mm, 5 mm to 15 mm, 5 mm to 20 mm, 5 mm to 25 mm, 5 mm to 30 mm, 5 mm to 40 mm, 5 mm to 50 mm, 5 mm to 100 mm, 5 mm to 250 mm, 5 mm to 500 mm, 5 mm to 1,000 mm, 10 mm to 15 mm, 10 mm to 20 mm, 10 mm to 25 mm, 10 mm to 30 mm, 10 mm to 40 mm, 10 mm to 50 mm, 10 mm to 100 mm, 10 mm to 250 mm, 10 mm to 500 mm, 10 mm to 1,000 mm, 15 mm to 20 mm, 15 mm to 25 mm, 15 mm to 30 mm, 15 mm to 40 mm, 15 mm to 50 mm, 15 mm to 100 mm, 15 mm to 250 mm, 15 mm to 500 mm, 15 mm to 1,000 mm, 20 mm to 25 mm, 20 mm to 30 mm, 20 mm to 40 mm, 20 mm to 50 mm, 20 mm to 100 mm, 20 mm to 250 mm, 20 mm to 500 mm, 20 mm to 1,000 mm, 25 mm to 30 mm, 25 mm to 40 mm, 25 mm to 50 mm, 25 mm to 100 mm, 25 mm to 250 mm, 25 mm to 500 mm, 25 mm to 1,000 mm, 30 mm to 40 mm, 30 mm to 50 mm, 30 mm to 100 mm, 30 mm to 250 mm, 30 mm to 500 mm, 30 mm to 1,000 mm, 40 mm to 50 mm, 40 mm to 100 mm, 40 mm to 250 mm, 40 mm to 500 mm, 40 mm to 1,000 mm, 50 mm to 100 mm, 50 mm to 250 mm, 50 mm to 500 mm, 50 mm to 1,000 mm, 100 mm to 250 mm, 100 mm to 500 mm, 100 mm to 1,000 mm, 250 mm to 500 mm, 250 mm to 1,000 mm, or 500 mm to 1,000 mm.

In some embodiments, the (e.g. axial) height **122** of an undeformed first chamber can be 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 40 mm, 50 mm, 100 mm, 250 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. axial) height **122** of an undeformed first chamber can be at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 40 mm, 50 mm, 100 mm, 250 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. axial) height **122** of an undeformed first chamber can be at most 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 40 mm, 50 mm, 100 mm, 250 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. maximum) width of an energy absorption device **100** is 5 mm to 1,000 mm.

In some embodiments, the (e.g. maximum) width of an energy absorption device **100** can be 5 mm to 10 mm, 5 mm to 15 mm, 5 mm to 20 mm, 5 mm to 25 mm, 5 mm to 30 mm, 5 mm to 40 mm, 5 mm to 50 mm, 5 mm to 100 mm, 5 mm to 250 mm, 5 mm to 500 mm, 5 mm to 1,000 mm, 10 mm to 15 mm, 10 mm to 20 mm, 10 mm to 25 mm, 10 mm to 30 mm, 10 mm to 40 mm, 10 mm to 50 mm, 10 mm to 100 mm, 10 mm to 250 mm, 10 mm to 500 mm, 10 mm to 1,000 mm, 15 mm to 20 mm, 15 mm to 25 mm, 15 mm to 30 mm, 15 mm to 40 mm, 15 mm to 50 mm, 15 mm to 100 mm, 15 mm to 250 mm, 15 mm to 500 mm, 15 mm to 1,000 mm, 20 mm to 25 mm, 20 mm to 30 mm, 20 mm to 40 mm, 20 mm to 50 mm, 20 mm to 100 mm, 20 mm to 250 mm, 20 mm to 500 mm, 20 mm to 1,000 mm, 25 mm to 30 mm, 25 mm to 40 mm, 25 mm to 50 mm, 25 mm to 100 mm, 25 mm to 250 mm, 25 mm to 500 mm, 25 mm to 1,000 mm, 30 mm to 40 mm, 30 mm to 50 mm, 30 mm to 100 mm, 30 mm to 250 mm, 30 mm to 500 mm, 30 mm to 1,000 mm, 40 mm to 50 mm, 40 mm to 100 mm, 40 mm to 250 mm, 40 mm to 500 mm, 40 mm to 1,000 mm, 50 mm to 100 mm, 50 mm to 250 mm, 50 mm to 500 mm, 50 mm to 1,000 mm, 100 mm to 250 mm, 100 mm to 500 mm, 100 mm to 1,000 mm, 250 mm to 500 mm, 250 mm to 1,000 mm, or 500 mm to 1,000 mm.

In some embodiments, the (e.g. maximum) width of an energy absorption device **100** can be 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 40 mm, 50 mm, 100 mm, 250 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. maximum) width of an energy absorption device **100** can be at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 40 mm, 50 mm, 100 mm, 250 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. maximum) width of an energy absorption device **100** can be at most 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 40 mm, 50 mm, 100 mm, 250 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber (e.g. perpendicular to a longitudinal axis **106**) can be 5 mm to 1,000 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber can be 5 mm to 10 mm, 5 mm to 15 mm, 5 mm to 20 mm, 5 mm to 25 mm, 5 mm to 30 mm, 5 mm to 40 mm, 5 mm to 50 mm, 5 mm to 100 mm, 5 mm to 250 mm, 5 mm to 500 mm, 5 mm to 1,000 mm, 10 mm to 15 mm, 10 mm to 20 mm, 10 mm to 25 mm, 10 mm to 30 mm, 10 mm to 40 mm, 10 mm to 50 mm, 10 mm to 100 mm, 10 mm to 250 mm, 10 mm to 500 mm, 10 mm to 1,000 mm, 15 mm to 20 mm, 15 mm to 25 mm, 15 mm to 30 mm, 15 mm to 40 mm, 15 mm to 50 mm, 15 mm to 100 mm, 15 mm to 250 mm, 15 mm to 500 mm, 15 mm to 1,000 mm, 20 mm to 25 mm, 20 mm to 30 mm, 20 mm to 40 mm, 20 mm to 50 mm, 20 mm to 100 mm, 20 mm to 250 mm, 20 mm to 500 mm, 20 mm to 1,000 mm, 25 mm to 30 mm, 25 mm to 40 mm, 25 mm to 50 mm, 25 mm to 100 mm, 25 mm to 250 mm, 25 mm to 500 mm, 25 mm to 1,000 mm, 30 mm to 40 mm, 30 mm to 50 mm, 30 mm to 100 mm, 30 mm to 250 mm, 30 mm to 500 mm, 30 mm to 1,000 mm, 40 mm to 50 mm, 40 mm to 100 mm, 40 mm to 250 mm, 40 mm to 500 mm, 40 mm to 1,000 mm, 50 mm to 100 mm, 50 mm to 250 mm, 50 mm to 500 mm, 50 mm to 1,000 mm, 100 mm to 250 mm, 100 mm to 500 mm, 100 mm to 1,000 mm, 250 mm to 500 mm, 250 mm to 1,000 mm, or 500 mm to 1,000 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber can be 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 40 mm, 50 mm, 100 mm, 250 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber can be at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 40 mm, 50 mm, 100 mm, 250 mm, or 500 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber can be at most 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 40 mm, 50 mm, 100 mm, 250 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber (e.g. perpendicular to a longitudinal axis **106**) can be 5 mm to 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber can be 5 mm to 10 mm, 5 mm to 15 mm, 5 mm to 20 mm, 5 mm to 25 mm, 5 mm to 30 mm, 5 mm to 35 mm, 5 mm to 40 mm, 5 mm to 45 mm, 5 mm to 50 mm, 5 mm to 55 mm, 5 mm to 60 mm, 10 mm to 15 mm, 10 mm to 20 mm, 10 mm to 25 mm, 10 mm to 30 mm, 10 mm to 35 mm, 10 mm to 40 mm, 10 mm to 45 mm, 10 mm to 50 mm, 10 mm to 55 mm, 10 mm to 60 mm, 15 mm to 20 mm, 15 mm to 25 mm, 15 mm to 30 mm, 15 mm to 35 mm, 15 mm to 40 mm, 15 mm to 45 mm, 15 mm to 50 mm, 15 mm to 55 mm, 15 mm to 60 mm, 20 mm to 25 mm, 20 mm to 30 mm, 20 mm to 35 mm, 20 mm to 40 mm, 20 mm to 45 mm, 20 mm to 50 mm, 20 mm to 55 mm, 20 mm to 60 mm, 25 mm to 30 mm, 25 mm to 35 mm, 25 mm to 40 mm, 25 mm to 45 mm, 25 mm to 50 mm, 25 mm to 55 mm, 25 mm to 60 mm, 30 mm to 35 mm, 30 mm to 40 mm, 30 mm to 45 mm, 30 mm to 50 mm, 30 mm to 55 mm, 30 mm to 60 mm, 35 mm to 40 mm, 35 mm to 45 mm, 35 mm to 50 mm, 35 mm to 55 mm, 35 mm to 60 mm, 40 mm to 45 mm, 40 mm to 50 mm, 40 mm to 55 mm, 40 mm to 60 mm, 45 mm to 50 mm, 45 mm to 55 mm, 45 mm to 60 mm, 50 mm to 55 mm, 50 mm to 60 mm, or 55 mm to 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber can be 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber can be at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber can be at most 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width **124** of an undeformed first chamber (e.g. perpendicular to a longitudinal axis **106**) at a first (e.g. distal) end can be 5 mm to 60 mm.

In some embodiments, the (e.g. maximum) width **124** of an undeformed first chamber at a first (e.g. distal) end can be 5 mm to 10 mm, 5 mm to 15 mm, 5 mm to 20 mm, 5 mm to 25 mm, 5 mm to 30 mm, 5 mm to 35 mm, 5 mm to 40 mm, 5 mm to 45 mm, 5 mm to 50 mm, 5 mm to 55 mm, 5 mm to 60 mm, 10 mm to 15 mm, 10 mm to 20 mm, 10 mm to 25 mm, 10 mm to 30 mm, 10 mm to 35 mm, 10 mm to 40 mm, 10 mm to 45 mm, 10 mm to 50 mm, 10 mm to 55 mm, 10 mm to 60 mm, 15 mm to 20 mm, 15 mm to 25 mm, 15 mm to 30 mm, 15 mm to 35 mm, 15 mm to 40 mm, 15 mm to 45 mm, 15 mm to 50 mm, 15 mm to 55 mm, 15 mm to 60 mm, 20 mm to 25 mm, 20 mm to 30 mm, 20 mm to 35 mm, 20 mm to 40 mm, 20 mm to 45 mm, 20 mm to 50 mm, 20 mm to 55 mm, 20 mm to 60 mm, 25 mm to 30 mm, 25 mm to 35 mm, 25 mm to 40 mm, 25 mm to 45 mm, 25 mm to 50 mm, 25 mm to 55 mm, 25 mm to 60 mm, 30 mm to 35 mm, 30 mm to 40 mm, 30 mm to 45 mm, 30 mm to 50 mm, 30 mm to 55 mm, 30 mm to 60 mm, 35 mm to 40 mm, 35 mm to 45 mm, 35 mm to 50 mm, 35 mm to 55 mm, 35 mm to 60 mm, 40 mm to 45 mm, 40 mm to 50 mm, 40 mm to 55 mm, 40 mm to 60 mm, 45 mm to 50 mm, 45 mm to 55 mm, 45 mm to 60 mm, 50 mm to 55 mm, 50 mm to 60 mm, or 55 mm to 60 mm.

In some embodiments, the (e.g. maximum) width **124** of an undeformed first chamber at a first (e.g. distal) end can be 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width **124** of an undeformed first chamber at a first (e.g. distal) end can be at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width **124** of an undeformed first chamber at a first (e.g. distal) end can be at most 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width **126** of an undeformed first chamber at a second (e.g. proximal) end can be 5 mm to 60 mm.

In some embodiments, the (e.g. maximum) width **126** of an undeformed first chamber at a second (e.g. proximal) end can be 5 mm to 10 mm, 5 mm to 15 mm, 5 mm to 20 mm, 5 mm to 25 mm, 5 mm to 30 mm, 5 mm to 35 mm, 5 mm to 40 mm, 5 mm to 45 mm, 5 mm to 50 mm, 5 mm to 55 mm, 5 mm to 60 mm, 10 mm to 15 mm, 10 mm to 20 mm, 10 mm to 25 mm, 10 mm to 30 mm, 10 mm to 35 mm, 10 mm to 40 mm, 10 mm to 45 mm, 10 mm to 50 mm, 10 mm to 55 mm, 10 mm to 60 mm, 15 mm to 20 mm, 15 mm to 25 mm, 15 mm to 30 mm, 15 mm to 35 mm, 15 mm to 40 mm, 15 mm to 45 mm, 15 mm to 50 mm, 15 mm to 55 mm, 15 mm to 60 mm, 20 mm to 25 mm, 20 mm to 30 mm, 20 mm to 35 mm, 20 mm to 40 mm, 20 mm to 45 mm, 20 mm to 50 mm, 20 mm to 55 mm, 20 mm to 60 mm, 25 mm to 30 mm, 25 mm to 35 mm, 25 mm to 40 mm, 25 mm to 45 mm, 25 mm to 50 mm, 25 mm to 55 mm, 25 mm to 60 mm, 30 mm to 35 mm, 30 mm to 40 mm, 30 mm to 45 mm, 30 mm to 50 mm, 30 mm to 55 mm, 30 mm to 60 mm, 35 mm to 40 mm, 35 mm to 45 mm, 35 mm to 50 mm, 35 mm to 55 mm, 35 mm to 60 mm, 40 mm to 45 mm, 40 mm to 50 mm, 40 mm to 55 mm, 40 mm to 60 mm, 45 mm to 50 mm, 45 mm to 55 mm, 45 mm to 60 mm, 50 mm to 55 mm, 50 mm to 60 mm, or 55 mm to 60 mm.

In some embodiments, the (e.g. maximum) width **126** of an undeformed first chamber at a second (e.g. proximal) end can be 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width **126** of an undeformed first chamber at a second (e.g. proximal) end can be at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, or 55 mm.

In some embodiments, the (e.g. maximum) width **126** of an undeformed first chamber at a second (e.g. proximal) end can be at most 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 5 mm to 60 mm can be 5 mm to 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 5 mm to 60 mm can be 5 mm to 10 mm, 5 mm to 15 mm, 5 mm to 20 mm, 5 mm to 25 mm, 5 mm to 30 mm, 5 mm to 35 mm, 5 mm to 40 mm, 5 mm to 45 mm, 5 mm to 50 mm, 5 mm to 55 mm, 5 mm to 60 mm, 10 mm to 15 mm, 10 mm to 20 mm, 10 mm to 25 mm, 10 mm to 30 mm, 10 mm to 35 mm, 10 mm to 40 mm, 10 mm to 45 mm, 10 mm to 50 mm, 10 mm to 55 mm, 10 mm to 60 mm, 15 mm to 20 mm, 15 mm to 25 mm, 15 mm to 30 mm, 15 mm to 35 mm, 15 mm to 40 mm, 15 mm to 45 mm, 15 mm to 50 mm, 15 mm to 55 mm, 15 mm to 60 mm, 20 mm to 25 mm, 20 mm to 30 mm, 20 mm to 35 mm, 20 mm to 40 mm, 20 mm to 45 mm, 20 mm to 50 mm, 20 mm to 55 mm, 20 mm to 60 mm, 25 mm to 30 mm, 25 mm to 35 mm, 25 mm to 40 mm, 25 mm to 45 mm, 25 mm to 50 mm, 25 mm to 55 mm, 25 mm to 60 mm, 30 mm to 35 mm, 30 mm to 40 mm, 30 mm to 45 mm, 30 mm to 50 mm, 30 mm to 55 mm, 30 mm to 60 mm, 35 mm to 40 mm, 35 mm to 45 mm, 35 mm to 50 mm, 35 mm to 55 mm, 35 mm to 60 mm, 40 mm to 45 mm, 40 mm to 50 mm, 40 mm to 55 mm, 40 mm to 60 mm, 45 mm to 50 mm, 45 mm to 55 mm, 45 mm to 60 mm, 50 mm to 55 mm, 50 mm to 60 mm, or 55 mm to 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 5 mm to 60 mm can be 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 5 mm to 60 mm can be at least 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 5 mm to 60 mm can be at most 5 mm, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, 50 mm, 55 mm, or 60 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 60 mm to 1,000 mm can be 5 mm to 1,000 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 60 mm to 1,000 mm can be 5 mm to 10 mm, 5 mm to 25 mm, 5 mm to 50 mm, 5 mm to 60 mm, 5 mm to 75 mm, 5 mm to 100 mm, 5 mm to 200 mm, 5 mm to 300 mm, 5 mm to 400 mm, 5 mm to 500 mm, 5 mm to 1,000 mm, 10 mm to 25 mm, 10 mm to 50 mm, 10 mm to 60 mm, 10 mm to 75 mm, 10 mm to 100 mm, 10 mm to 200 mm, 10 mm to 300 mm, 10 mm to 400 mm, 10 mm to 500 mm, 10 mm to 1,000 mm, 25 mm to 50 mm, 25 mm to 60 mm, 25 mm to 75 mm, 25 mm to 100 mm, 25 mm to 200 mm, 25 mm to 300 mm, 25 mm to 400 mm, 25 mm to 500 mm, 25 mm to 1,000 mm, 50 mm to 60 mm, 50 mm to 75 mm, 50 mm to 100 mm, 50 mm to 200 mm, 50 mm to 300 mm, 50 mm to 400 mm, 50 mm to 500 mm, 50 mm to 1,000 mm, 60 mm to 75 mm, 60 mm to 100 mm, 60 mm to 200 mm, 60 mm to 300 mm, 60 mm to 400 mm, 60 mm to 500 mm, 60 mm to 1,000 mm, 75 mm to 100 mm, 75 mm to 200 mm, 75 mm to 300 mm, 75 mm to 400 mm, 75 mm to 500 mm, 75 mm to 1,000 mm, 100 mm to 200 mm, 100 mm to 300 mm, 100 mm to 400 mm, 100 mm to 500 mm, 100 mm to 1,000 mm, 200 mm to 300 mm, 200 mm to 400 mm, 200 mm to 500 mm, 200 mm to 1,000 mm, 300 mm to 400 mm, 300 mm to 500 mm, 300 mm to 1,000 mm, 400 mm to 500 mm, 400 mm to 1,000 mm, or 500 mm to 1,000 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 60 mm to 1,000 mm can be 5 mm, 10 mm, 25 mm, 50 mm, 60 mm, 75 mm, 100 mm, 200 mm, 300 mm, 400 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 60 mm to 1,000 mm can be at least 5 mm, 10 mm, 25 mm, 50 mm, 60 mm, 75 mm, 100 mm, 200 mm, 300 mm, 400 mm, 500 mm, or 1,000 mm.

In some embodiments, the (e.g. maximum) width of an undeformed first chamber of an energy absorption device having an (e.g. maximum) height of 60 mm to 1,000 mm can be at most 5 mm, 10 mm, 25 mm, 50 mm, 60 mm, 75 mm, 100 mm, 200 mm, 300 mm, 400 mm, 500 mm, or 1,000 mm.

In some cases, a cross-sectional width of a chamber (e.g. a width of a first chamber **120** and/or a second chamber **110** perpendicular to a device's longitudinal axis) is constant along all or a portion of the axial height of the chamber (e.g. as shown in FIG. **1**A, FIG. **7**A, FIG. **8**A, and FIG. **8**I). In some cases, a cross-sectional width of a chamber (e.g. a width of a first chamber **120** and/or a second chamber **110** perpendicular to a device's longitudinal axis) is not constant along all or a portion of the axial height of the chamber (e.g. as shown in FIG. **8**C, FIG. **8**E, FIG. **8**G, and FIG. **15**A). In some cases, a cross-sectional width of a chamber (e.g. a width of a first chamber **120** and/or a second chamber **110** perpendicular to a device's longitudinal axis) decreases along all or a portion of the axial height of the chamber with increasing distance from a proximal end of the device (e.g. as shown in FIG. **8**E, FIG. **8**G, FIG. and FIG. **15**A). In some cases, a cross-sectional width of a chamber (e.g. a width of a first chamber **120** and/or a second chamber **110** perpendicular to a device's longitudinal axis) decreases linearly along all or a portion of the axial height of the chamber with increasing distance from a proximal end of the device (e.g. as shown in FIG. **8**G). In some cases, a cross-sectional width of a chamber (e.g. a width of a first chamber **120** and/or a second chamber **110** perpendicular to a device's longitudinal axis) decreases non-linearly along all or a portion of the axial height of the chamber with increasing distance from a proximal end of the device (e.g. as shown in FIG. **8**E, and FIG. **15**A.

In some cases, an energy absorption device **100** comprises a means of creating backpressure on a fluid of the device (e.g. pressure on a fluid of the device rectified from an interstitial volume **132** toward an interior volume **128** of a first chamber **120**), for example when the device is undeformed and/or wherein an external force is not acting upon the device. In some cases, creating a backpressure on a fluid of the device is advantageous because it ensures that the amount of fluid disposed within the first chamber **120** of an energy absorption device **100** is consistent regardless of the orientation or motion of the device at the time of external impact, which can improve the reproducibility of the device's performance and/or the conformity of the device's actual performance under a given real-world set of conditions to its expected performance. In some cases, the thickness, volume, and/or elasticity of the second chamber **110** can be selected to create a backpressure on a fluid disposed within the device (e.g. when the device is undeformed and/or wherein an external force is not acting upon the device). In some cases, the amount (e.g. volume) of fluid disposed within the device relative to the interior volume **128** of the first chamber **120** and/or the interstitial volume **132** is selected (e.g. along with the elasticity of a wall **111** of a second chamber **110**) to produce a desired backpressure on the fluid of the device (e.g. when the device is undeformed and/or wherein an external force is not acting upon the device). In some cases, the dimensions of the second chamber (e.g. and of wall **111**), the volume of a fluid disposed within the energy absorption device, and the material properties (e.g. elasticity) of wall **111** are selected to produce a desired backpressure on the fluid of the device (e.g. when the device is undeformed and/or wherein an external force is not acting upon the device). In some cases, an energy absorption device **100** comprises a third chamber **150** (e.g. a backpressure chamber) disposed around at least a portion of the first chamber **120** and/or second chamber **110** of the device (e.g. as shown in FIG. **9**B). In some cases, a wall **151** of the third chamber **150** is coupled to a wall **121** of a first chamber and/or to a wall **111** of a second chamber **110**, e.g. to form a chamber **150** having a backpressure volume **152** isolated from the interior volume **128** of the first chamber **120** and the interstitial volume **132**. In some cases, the interior of a third chamber **150** (e.g. the backpressure volume **152**) of the device comprises a fluid (e.g. gas and/or liquid, such as an incompressible fluid). In some cases, a wall **151** of the third chamber **150** is rigid. In some cases, a wall **151** of the third chamber **150** is flexible. In some cases, the dimensions of the third chamber **150** (e.g. of a wall **151** of the third chamber **150** and/or the size of the backpressure volume **152** disposed within the third chamber **150**, for example, relative to the dimensions of the first chamber **120** and/or second chamber **110**), the amount of fluid disposed within the interior volume **152** of the third chamber **150**, and the elasticity of the wall **151** of the third chamber **150** are selected to produce a desired backpressure on a fluid (e.g. an incompressible fluid) disposed within the interior volume **128** and/or within the interstitial volume **132** of an energy absorption device **100**.

In some cases, a wall (e.g. wall **121**, wall **111**, interstitial material **130**, and/or a wall **151** of a third chamber **150** of an energy absorption device **100**) can comprise one or more bands disposed therein having a different dimension (e.g. larger maximum circumference) and/or different elasticity or tensile strength than the wall in which the one or more bands are disposed. In some cases, a wall comprising one or more bands disposed therein having a different dimension (e.g. larger maximum circumference) and/or different elasticity or tensile strength can allow fine-tuning of the resistance to deformation of the wall (e.g. via recruitment of the one or more bands as the wall deforms, for example, in a radial direction away from a longitudinal axis of the device). In this way, the composition of one or more walls of an energy absorption device can be engineered to provide a desired resistance profile over the course of the wall's deformation (e.g. wherein the wall is designed to exert a continuous (linear or non-linear) or stepped resistance profile over the course of the wall's deformation.

A wall **121** of a first chamber **120** can be made of a collapsible material. In many cases, wall **121** of a first chamber can comprise a flexible material. For example, a wall **121** of a first chamber can comprise silicone. In some cases, a wall **121** of a first chamber **120** can comprise a molded silicone. A wall **111** of a second chamber **110** can be made of a collapsible material. In many cases, wall **111** of a second chamber **110** can comprise a flexible material. For example, a wall **111** of a first chamber can comprise a polymer or a composite. For example, a wall **111** of a first chamber can comprise latex, neoprene, or synthetic rubber, such as silicone (e.g. a cured silicone rubber, e.g. having a shore A hardness between 00-30 or 00-30 A).

In some embodiments, a wall of an energy absorption device (e.g. wall **121**, wall **111**, or interstitial material **130**) can have a thickness of 0.1 mm to 10 mm. In some embodiments, a wall of an energy absorption device (e.g. wall **121**, wall **111**, or interstitial material **130**) can have a thickness of 0.1 mm to 0.5 mm, 0.1 mm to 1 mm, 0.1 mm to 2 mm, 0.1 mm to 3 mm, 0.1 mm to 4 mm, 0.1 mm to 5 mm, 0.1 mm to 6 mm, 0.1 mm to 7 mm, 0.1 mm to 8 mm, 0.1 mm to 9 mm, 0.1 mm to 10 mm, 0.5 mm to 1 mm, 0.5 mm to 2 mm, 0.5 mm to 3 mm, 0.5 mm to 4 mm, 0.5 mm to 5 mm, 0.5 mm to 6 mm, 0.5 mm to 7 mm, 0.5 mm to 8 mm, 0.5 mm to 9 mm, 0.5 mm to 10 mm, 1 mm to 2 mm, 1 mm to 3 mm, 1 mm to 4 mm, 1 mm to 5 mm, 1 mm to 6 mm, 1 mm to 7 mm, 1 mm to 8 mm, 1 mm to 9 mm, 1 mm to 10 mm, 2 mm to 3 mm, 2 mm to 4 mm, 2 mm to 5 mm, 2 mm to 6 mm, 2 mm to 7 mm, 2 mm to 8 mm, 2 mm to 9 mm, 2 mm to 10 mm, 3 mm to 4 mm, 3 mm to 5 mm, 3 mm to 6 mm, 3 mm to 7 mm, 3 mm to 8 mm, 3 mm to 9 mm, 3 mm to 10 mm, 4 mm to 5 mm, 4 mm to 6 mm, 4 mm to 7 mm, 4 mm to 8 mm, 4 mm to 9 mm, 4 mm to 10 mm, 5 mm to 6 mm, 5 mm to 7 mm, 5 mm to 8 mm, 5 mm to 9 mm, 5 mm to 10 mm, 6 mm to 7 mm, 6 mm to 8 mm, 6 mm to 9 mm, 6 mm to 10 mm, 7 mm to 8 mm, 7 mm to 9 mm, 7 mm to 10 mm, 8 mm to 9 mm, 8 mm to 10 mm, or 9 mm to 10 mm.

In some embodiments, a wall of an energy absorption device can have a thickness of 0.1 mm, 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, or 10 mm.

In some embodiments, a wall of an energy absorption device can have a thickness of at least 0.1 mm, 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, or 10 mm.

In some embodiments, a wall of an energy absorption device can have a thickness of at most 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, or 10 mm.

In some cases, a material of a structure (e.g. wall **121**, wall **111**, or interstitial material **130**) of an energy can be selected to provide the structure with a stiffness in a desirable range.

In some embodiments, a wall (or portion thereof) of an energy absorption device can have a stiffness of 0.5 MPa to 500 MPa.

In some embodiments, a wall (or portion thereof) of an energy absorption device can have a stiffness of 0.5 MPa to 1 MPa, 0.5 MPa to 1.5 MPa, 0.5 MPa to 2 MPa, 0.5 MPa to 2.5 MPa, 0.5 MPa to 5 MPa, 0.5 MPa to 7.5 MPa, 0.5 MPa to 10 MPa, 0.5 MPa to 20 MPa, 0.5 MPa to 50 MPa, 0.5 MPa to 100 MPa, 0.5 MPa to 500 MPa, 1 MPa to 1.5 MPa, 1 MPa to 2 MPa, 1 MPa to 2.5 MPa, 1 MPa to 5 MPa, 1 MPa to 7.5 MPa, 1 MPa to 10 MPa, 1 MPa to 20 MPa, 1 MPa to 50 MPa, 1 MPa to 100 MPa, 1 MPa to 500 MPa, 1.5 MPa to 2 MPa, 1.5 MPa to 2.5 MPa, 1.5 MPa to 5 MPa, 1.5 MPa to 7.5 MPa, 1.5 MPa to 10 MPa, 1.5 MPa to 20 MPa, 1.5 MPa to 50 MPa, 1.5 MPa to 100 MPa, 1.5 MPa to 500 MPa, 2 MPa to 2.5 MPa, 2 MPa to 5 MPa, 2 MPa to 7.5 MPa, 2 MPa to 10 MPa, 2 MPa to 20 MPa, 2 MPa to 50 MPa, 2 MPa to 100 MPa, 2 MPa to 500 MPa, 2.5 MPa to 5 MPa, 2.5 MPa to 7.5 MPa, 2.5 MPa to 10 MPa, 2.5 MPa to 20 MPa, 2.5 MPa to 50 MPa, 2.5 MPa to 100 MPa, 2.5 MPa to 500 MPa, 5 MPa to 7.5 MPa, 5 MPa to 10 MPa, 5 MPa to 20 MPa, 5 MPa to 50 MPa, 5 MPa to 100 MPa, 5 MPa to 500 MPa, 7.5 MPa to 10 MPa, 7.5 MPa to 20 MPa, 7.5 MPa to 50 MPa, 7.5 MPa to 100 MPa, 7.5 MPa to 500 MPa, 10 MPa to 20 MPa, 10 MPa to 50 MPa, 10 MPa to 100 MPa, 10 MPa to 500 MPa, 20 MPa to 50 MPa, 20 MPa to 100 MPa, 20 MPa to 500 MPa, 50 MPa to 100 MPa, 50 MPa to 500 MPa, or 100 MPa to 500 MPa.

In some embodiments, a wall (or portion thereof) of an energy absorption device can have a stiffness of 0.5 MPa, 1 MPa, 1.5 MPa, 2 MPa, 2.5 MPa, 5 MPa, 7.5 MPa, 10 MPa, 20 MPa, 50 MPa, 100 MPa, or 500 MPa.

In some embodiments, a wall (or portion thereof) of an energy absorption device can have a stiffness of at least 0.5 MPa, 1 MPa, 1.5 MPa, 2 MPa, 2.5 MPa, 5 MPa, 7.5 MPa, 10 MPa, 20 MPa, 50 MPa, 100 MPa, or 500 MPa.

In some embodiments, a wall (or portion thereof) of an energy absorption device can have a stiffness of at most 1 MPa, 1.5 MPa, 2 MPa, 2.5 MPa, 5 MPa, 7.5 MPa, 10 MPa, 20 MPa, 50 MPa, 100 MPa, or 500 MPa.

Systems

Provided herein are systems **200** for absorbing energy (e.g. from an external impact force). In many cases, a system **200** for absorbing energy can comprise one or more force absorbing devices **100** (e.g. energy absorption devices) disclosed herein. For example, a system **200** for absorbing energy can comprise a plurality of energy absorption devices **100** (e.g. as shown in FIG. **17**A-FIG. **17**E). A system **200** can comprise 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, from 20 to 25, from 25 to 30, from 30 to 40, from 40 to 50, from 50 to 75, from 75 to 100, from 100 to 150, from 150 to 200, from 200 to 250, from 250 to 500, from 500 to 1,000, from 1,000 to 2,500, from 2,500 to 5,000, from 5,000 to 10,000, or more than 10,000 energy absorption devices **100**. In many cases, energy absorbing devices provided herein are self-contained and compact, making it easy to provide and arrange a plurality of individual energy absorption devices **100** on or in close proximity to an object to which shock impacts will be delivered. For example, a plurality of energy absorption devices **100** can be coupled to a solid support to increase the distribution of a force or pressure applied to the solid support (e.g. a helmet shell), which can lessen the magnitude and/or rate at which an object cushioned by the system experiences the applied (e.g. impact) force or pressure.

One or more energy absorption devices **100** can be permanently coupled to a solid support. For example, a plurality of energy absorption devices **100** can be permanently coupled to a solid support. In some cases, permanently coupling one or more energy absorption devices **100** to a solid support can allow for the one or more energy absorption devices **100** to be more securely attached to the solid support than if the one or more energy absorption devices were not permanently coupled to the solid support. In some cases, attaching one or more energy absorption devices **100** more securely to a solid support can help to keep the one or more energy absorption devices in a desired position or arrangement with respect to the solid support. In some cases, maintaining the one or more energy absorption devices **100** in a desired position or arrangement with respect to the solid support helps to maintain consistent energy absorption by the system.

In some cases, one or more energy absorption devices **100** of a system disclosed herein are directly coupled to the solid support. In some cases, one or more energy absorption devices **100** of a system disclosed herein are indirectly coupled to the solid support **190**. In some cases, one or more energy absorption devices **100** of a system disclosed herein are coupled to an intermediate support that is connected to the solid support **190** at one or more coupling locations. In some cases, an intermediate support is rigid. In some cases, an intermediate support is non-rigid. For example, an intermediate support can comprise a webbing or netting coupled to one or more energy absorption devices **100** of system **200**, e.g. wherein the intermediate support is also coupled to a solid support **190** of the system **200**. In some cases, one or more energy absorption devices coupled to an intermediate support are not directly coupled to the solid support **190**.

One or more energy absorption devices **100** can be detachably coupled to a solid support. For example, a plurality of energy absorption devices **100** can be detachably coupled to a solid support. In some cases, detachably coupling one or more energy absorption devices **100** to a solid support can allow for rearrangement and/or replacement of the one or more energy absorption devices. In some cases, rearrangement and/or replacement of the one or more energy absorption devices **100** on a solid support can allow the pattern or configuration of energy absorption devices on the solid support to be changed, e.g. to improve absorption of energy transmitted to the system via different external forces or pressures or during different applications (e.g. where the solid support is expected to be loaded differently or where the characteristics of the object protected by the system have changed). In some cases, detachably coupling one or more energy absorption devices **100** to a solid support allows replacement of an energy absorption device **100** (or a plurality of energy absorption devices) of the one or more energy absorption devices **100** (e.g. after failure, for example, due to material fatigue or over-pressurization) without requiring that the entire system be replaced. For example, if an athletic helmet comprising a plurality of energy absorption devices **100** experiences a failure of a one or more of the plurality of energy absorption devices, the one or more failed energy absorption devices can be replaced without the need to replace all of the energy absorption devices or the entire helmet. In some cases, one or more energy absorption devices **100** of a system for absorbing energy can be replaced with one or more energy absorption devices to change the density of energy absorption devices in a region of the system or to change the characteristics of the one or more energy absorption devices in a region of the system (e.g. increasing or decreasing the energy absorption rate in the region of the system by replacing the one or more energy absorption devices with one or more energy absorption devices having, for example, different dimensions, thicker or more resilient wall(s) of the first chamber, more elastic wall(s) of the second chamber than the original one or more energy absorption devices of the system).

In some cases, a system for absorbing energy comprises a first solid support coupled to a first end **102** of each of one or more energy absorption devices **100** and a second solid support coupled to a second end **104** of the one or more energy absorption devices **100**. In some cases, the first solid support is subjected to an external force or pressure (e.g. an external shock impact) and the second support aids in distributing a force or pressure transmitted through the one or more energy absorption devices across a surface of an object to be cushioned from the external force or pressure.

A solid support **190** used in a device **100** or system **200** described herein can be a linear elastic material. For example, a solid support can be a hard plastic or composite material. In many cases, a solid support is selected to have a stiffness higher than that of the overall stiffness of an energy absorption device **100** (e.g. under shock impact). In some embodiments, a solid support can have a stiffness of 0.5 GPa to 100 GPa.

In some embodiments, a solid support can have a stiffness of 0.5 GPa to 1 GPa, 0.5 GPa to 1.5 GPa, 0.5 GPa to 2 GPa, 0.5 GPa to 2.5 GPa, 0.5 GPa to 5 GPa, 0.5 GPa to 7.5 GPa, 0.5 GPa to 10 GPa, 0.5 GPa to 20 GPa, 0.5 GPa to 50 GPa, 0.5 GPa to 100 GPa, 1 GPa to 1.5 GPa, 1 GPa to 2 GPa, 1 GPa to 2.5 GPa, 1 GPa to 5 GPa, 1 GPa to 7.5 GPa, 1 GPa to 10 GPa, 1 GPa to 20 GPa, 1 GPa to 50 GPa, 1 GPa to 100 GPa, 1.5 GPa to 2 GPa, 1.5 GPa to 2.5 GPa, 1.5 GPa to 5 GPa, 1.5 GPa to 7.5 GPa, 1.5 GPa to 10 GPa, 1.5 GPa to 20 GPa, 1.5 GPa to 50 GPa, 1.5 GPa to 100 GPa, 2 GPa to 2.5 GPa, 2 GPa to 5 GPa, 2 GPa to 7.5 GPa, 2 GPa to 10 GPa, 2 GPa to 20 GPa, 2 GPa to 50 GPa, 2 GPa to 100 GPa, 2.5 GPa to 5 GPa, 2.5 GPa to 7.5 GPa, 2.5 GPa to 10 GPa, 2.5 GPa to 20 GPa, 2.5 GPa to 50 GPa, 2.5 GPa to 100 GPa, 5 GPa to 7.5 GPa, 5 GPa to 10 GPa, 5 GPa to 20 GPa, 5 GPa to 50 GPa, 5 GPa to 100 GPa, 7.5 GPa to 10 GPa, 7.5 GPa to 20 GPa, 7.5 GPa to 50 GPa, 7.5 GPa to 100 GPa, 10 GPa to 20 GPa, 10 GPa to 50 GPa, 10 GPa to 100 GPa, 20 GPa to 50 GPa, 20 GPa to 100 GPa, or 50 GPa to 100 GPa.

In some embodiments, a solid support can have a stiffness of 0.5 GPa, 1 GPa, 1.5 GPa, 2 GPa, 2.5 GPa, 5 GPa, 7.5 GPa, 10 GPa, 20 GPa, 50 GPa, or 100 GPa.

In some embodiments, a solid support can have a stiffness of at least 0.5 GPa, 1 GPa, 1.5 GPa, 2 GPa, 2.5 GPa, 5 GPa, 7.5 GPa, 10 GPa, 20 GPa, 50 GPa, or 100 GPa.

In some embodiments, a solid support can have a stiffness of at most 1 GPa, 1.5 GPa, 2 GPa, 2.5 GPa, 5 GPa, 7.5 GPa, 10 GPa, 20 GPa, 50 GPa, or 100 GPa.

In some cases, a system **200** can comprise one or more pressure distribution plates **195**, for example, as shown in FIG. **18**E. In some cases, a pressure distribution plate **195** is coupled to a distal end of each of a plurality of energy absorption devices **100** as disclosed herein. In many cases, coupling a pressure distribution plate **195** to each of a plurality of energy absorption devices **100** helps to distribute the forces and/or pressures exerted on an object protected by the system **200** (e.g. and in contact with the distal end(s) of one or more of the plurality of energy absorption devices **100**) across a larger surface area of the object (e.g. to decrease the likelihood of damage to the object by decreasing pressure exerted on a portion of the object).

In some cases, a pressure distribution plate **195** is rigid. In some cases, a pressure distribution plate **195** is flexible (e.g. to provide a more form-fitting contact with the object to be protected by the system).

In some cases, a pressure distribution plate **195** is coupled to (e.g. a distal end of) 1 energy absorption device to 50 energy absorption devices.

In some cases, a pressure distribution plate **195** is coupled to (e.g. a distal end of) 1 energy absorption device to 2 energy absorption devices, 1 energy absorption device to 3 energy absorption devices, 1 energy absorption device to 4 energy absorption devices, 1 energy absorption device to 5 energy absorption devices, 1 energy absorption device to 6 energy absorption devices, 1 energy absorption device to 7 energy absorption devices, 1 energy absorption device to 8 energy absorption devices, 1 energy absorption device to 9 energy absorption devices, 1 energy absorption device to 10 energy absorption devices, 1 energy absorption device to 20 energy absorption devices, 1 energy absorption device to 50 energy absorption devices, 2 energy absorption devices to 3 energy absorption devices, 2 energy absorption devices to 4 energy absorption devices, 2 energy absorption devices to 5 energy absorption devices, 2 energy absorption devices to 6 energy absorption devices, 2 energy absorption devices to 7 energy absorption devices, 2 energy absorption devices to 8 energy absorption devices, 2 energy absorption devices to 9 energy absorption devices, 2 energy absorption devices to 10 energy absorption devices, 2 energy absorption devices to 20 energy absorption devices, 2 energy absorption devices to 50 energy absorption devices, 3 energy absorption devices to 4 energy absorption devices, 3 energy absorption devices to 5 energy absorption devices, 3 energy absorption devices to 6 energy absorption devices, 3 energy absorption devices to 7 energy absorption devices, 3 energy absorption devices to 8 energy absorption devices, 3 energy absorption devices to 9 energy absorption devices, 3 energy absorption devices to 10 energy absorption devices, 3 energy absorption devices to 20 energy absorption devices, 3 energy absorption devices to 50 energy absorption devices, 4 energy absorption devices to 5 energy absorption devices, 4 energy absorption devices to 6 energy absorption devices, 4 energy absorption devices to 7 energy absorption devices, 4 energy absorption devices to 8 energy absorption devices, 4 energy absorption devices to 9 energy absorption devices, 4 energy absorption devices to 10 energy absorption devices, 4 energy absorption devices to 20 energy absorption devices, 4 energy absorption devices to 50 energy absorption devices, 5 energy absorption devices to 6 energy absorption devices, 5 energy absorption devices to 7 energy absorption devices, 5 energy absorption devices to 8 energy absorption devices, 5 energy absorption devices to 9 energy absorption devices, 5 energy absorption devices to 10 energy absorption devices, 5 energy absorption devices to 20 energy absorption devices, 5 energy absorption devices to 50 energy absorption devices, 6 energy absorption devices to 7 energy absorption devices, 6 energy absorption devices to 8 energy absorption devices, 6 energy absorption devices to 9 energy absorption devices, 6 energy absorption devices to 10 energy absorption devices, 6 energy absorption devices to 20 energy absorption devices, 6 energy absorption devices to 50 energy absorption devices, 7 energy absorption devices to 8 energy absorption devices, 7 energy absorption devices to 9 energy absorption devices, 7 energy absorption devices to 10 energy absorption devices, 7 energy absorption devices to 20 energy absorption devices, 7 energy absorption devices to 50 energy absorption devices, 8 energy absorption devices to 9 energy absorption devices, 8 energy absorption devices to 10 energy absorption devices, 8 energy absorption devices to 20 energy absorption devices, 8 energy absorption devices to 50 energy absorption devices, 9 energy absorption devices to 10 energy absorption devices, 9 energy absorption devices to 20 energy absorption devices, 9 energy absorption devices to 50 energy absorption devices, 10 energy absorption devices to 20 energy absorption devices, 10 energy absorption devices to 50 energy absorption devices, or 20 energy absorption devices to 50 energy absorption devices.

In some cases, a pressure distribution plate **195** is coupled to (e.g. a distal end of) 1 energy absorption device, 2 energy absorption devices, 3 energy absorption devices, 4 energy absorption devices, 5 energy absorption devices, 6 energy absorption devices, 7 energy absorption devices, 8 energy absorption devices, 9 energy absorption devices, 10 energy absorption devices, 20 energy absorption devices, or 50 energy absorption devices.

In some cases, a pressure distribution plate **195** is coupled to (e.g. a distal end of) at least 1 energy absorption device, 2 energy absorption devices, 3 energy absorption devices, 4 energy absorption devices, 5 energy absorption devices, 6 energy absorption devices, 7 energy absorption devices, 8 energy absorption devices, 9 energy absorption devices, 10 energy absorption devices, 20 energy absorption devices, or at least 50 energy absorption devices.

In some cases, a pressure distribution plate **195** is coupled to (e.g. a distal end of) at most 1 energy absorption device, 2 energy absorption devices, 3 energy absorption devices, 4 energy absorption devices, 5 energy absorption devices, 6 energy absorption devices, 7 energy absorption devices, 8 energy absorption devices, 9 energy absorption devices, 10 energy absorption devices, 20 energy absorption devices, or 50 energy absorption devices.

In many embodiments, a system **200** comprises a plurality of pressure distribution plates **195**.

In some cases, one or more energy absorption devices **100** are coupled to a first support (e.g. a solid support **190**, for example, at a proximal end of the one or more devices) and to a second support (e.g. a pressure distribution plate, for example, at a distal end of the one or more devices).

In some cases, a system **200** can comprise an elastically compressible material **192**. In many cases, an elastically compressible material **192** is coupled to a solid support **190**. In some cases, the elastically compressible material helps to prevent bottoming out of the object to be protected under loading conditions comprising extreme impact forces and/or extreme impact velocities (e.g. after complete deformation or collapse of one or more energy absorption devices **100** of system **200**). In many cases, the elastically compressible material **192** is coupled to the solid support **190** adjacent to a proximal end of one or more energy absorption devices **100** coupled to the solid support **190** (e.g. if it is desired to limit the contribution of the elastically compressible material's deformation to the force and deformation profiles of the device during loading with an external force or pressure). In some cases, an elastically compressible material **192** comprises a foam (e.g. high-density foam or low-density foam) or polystyrene.

EXAMPLES

Evaluation of Force Profiles During Energy Absorption Device Compression

This example shows an evaluation of simulated and experimental force profiles of a cylindrical energy absorption device subjected to an external axial impact. A finite element model was used to predict changes is force exerted by a cylindrical energy absorption device, as described herein, over time. As shown in FIG. **10**A, the model predicted a biphasic force profile, wherein the initial rise and fall of exerted force is likely due to internal liquid pressure as the incompressible fluid is pushed out of the first chamber into the interstitial space via a plurality of orifices and a subsequent rise and fall of exerted force is likely due to buckling of the reinforced silicone wall and interstitial material. When orifice size was varied, it was found that a device having a 9 mm diameter orifice size provided the force curve with the least amount of change in force over time, as compared to 8.5 mm diameter orifices or a device having 8.0 mm diameter orifices (see FIG. **10**B).

Benchtop testing showed that energy absorption devices having orifice diameters of 15 mm, 18 mm, and 21 mm produced excellent force over-time and acceleration over time curves (see FIG. **11**A and FIG. **11**B, respectively), while 24 mm showed acceptable force over-time curves.

Comparison of Disclosed Energy Absorption Devices Versus Alternate Shock Absorption Technologies

This example shows a comparison of force-displacement curves for disclosed energy absorption devices **100**, solid foam shock absorption material, a buckling cone shock absorber, and an air damper. FIG. **12**A is a schematic showing force displacement of solid foam padding (gray shaded curve) and idealized shock absorbers (black line). Foam padding suffers from a sharp increase in force exertion at high displacement percentages and an inability to full displace (e.g. collapse), leaving volume **175** of the foam padding that is unusable for shock absorption. Experimental data shows that energy absorption devices **100** disclosed herein do not exhibit the force spike shown by foam padding (foam), air dampers (air), and buckling cone shock absorbers (cone) at impact velocities of 3.1 m/s and 4.3 m/s (see FIG. **12**B and FIG. **12**C, respectively). Energy absorption devices **100** disclosed herein also show more efficient use of the absorber volume (e.g. maximum percentage displacement) compared to alternatives with an identical height. At a higher velocity (e.g. 5.5 m/s, as shown in FIG. **12**D), energy absorption devices **100** disclosed herein exhibit force-displacement dynamics among the best measured, while air damper and foam padding absorbers suffer from high maximum force values and low maximum displacement.

Evaluation of Fabricated Energy Absorption Device Performance Versus Computational Modeling Predictions

This example shows evaluation of real-world energy absorption device performance versus performance predicted using computational modeling. Energy absorption devices having a cylindrical first chamber configuration were subjected to axial external impacts with velocities of 3.1 m/s, 4.2 m/s, and 5.5 m/s, and the recorded force data curves (Exp) (N=3) were graphed over time versus values predicted by a finite element computational model (FE) (see FIGS. **13**A-**13**C). The resulting graphs showed good agreement between real-world experiments and predicted values.

Constant Force Energy Absorber

This example shows constant force exertion by an energy absorption device during deformation. An energy absorption device was designed having the "volcano" geometry shown in FIG. **14**A with an initial height of 50 mm, an initial diameter at its proximal end of 50 mm and an initial diameter at its distal end of 22 mm to determine whether a variable contact area apparatus (VCAA) can be designed to exert a constant force under axial compression. Various additional "volcano" type VCAA devices were designed having different initial (e.g. undeformed) first chamber heights **112**, initial (e.g. undeformed) proximal end widths **116**, and different initial (e.g. undeformed) distal end widths **114** (see e.g. FIGS. **5**A-**5**D) were also designed. As shown in FIGS. **4**A-**4**C, the energy absorption device (e.g. damper) comprised an orifice on a proximal end surface of the first chamber through which fluid in the first chamber was able to flow into a second chamber located below a rigid support (not shown). FIG. **4**D shows the mathematically determined relationship between contact area (in mm^2) and displacement distance (in mm) for a first chamber **120** having a height of 50 mm.

Force profiles for the device were predicted using computer modeling. Contact area was shown to increase while force remained constant and pressure decreased with increasing percent displacement (in a proximal direction) of the distal end of the wall **121** of the first chamber (see FIG. **14**B). After this, computational models were used to predict the constant force levels achieved with the designed energy absorption device with a 15 kg mass impacting the distal end of the VCAA from a drop height of 15 mm, assuming a fluid within the first chamber of the VCAA having a density of 10^3 kg/m^3 (see FIG. **14**C). The duration of the constant force was also predicted for various impact velocities exerted on the VCAA (see FIG. **14**D). These results showed that the VCAA could be used to achieve constant force at low-, medium-, and high-impact velocities, indicating that VCAA designs can be used to avoid potentially damaging spikes and variation in acceleration exhibited by traditional shock absorber technologies, such as foam.

FIG. **15**A and FIG. **15**B show external and cutaway views of a finite element model of a "volcano" configured VCAA energy absorption device **100** having solid end caps that was used in finite element modeling simulations of axial impact compression. In these figures, a solid end cap is shown having a width (or diameter) equal to or substantially equal to the portion of the energy absorption device with which they are in contact. In some cases, at least a portion of an end cap can be rigid. In some cases, the entirety of an end cap is rigid. In some cases, a portion of an end cap can be flexible. In some cases, an end cap comprises a width or diameter larger than a width or diameter of the energy absorption device **100** or a portion thereof (e.g. a distal end of energy absorption device), for example to decrease the pressure exerted on an object protected by the energy absorption device. In some cases, the width or diameter of the end cap is 1.1 to 1.5 times larger, 1.5 to 2.0 times larger or larger than 2.0 times larger than the width or diameter of the energy absorption device (or portion thereof). FIG. **15**C shows the VCAA in the context of the axial compression test within the finite element model. FIG. **15**D shows a finite element model of a cylindrical energy absorption device used in the same finite element testing context. Force-displacement simulations show excellent performance from the VCAA at all three impact velocities (5 m/s, 7 m/s, and 9 m/s; see FIGS. **15**E, **15**F, and **15**G, respectively), with no force spikes evident and excellent maximum percent displacement. Cylindrical energy absorption devices showed acceptable results for all three testing conditions. Force over-time curves for impact velocities of 5 m/s, 7 m/s, and 9 m/s presented in FIG. **15**H, FIG. **15**I, and FIG. **15**J, respectively, also showed excellent results for the VCAA device, with no force spikes evident and relatively constant force exertion over time. Cylindrical energy absorption devices showed acceptable results for all three impact velocities. Pressure over time curves for impact velocities of 5 m/s, 7 m/s, and 9 m/s presented in FIG. **15**K, FIG. **15**L, and FIG. **15**M, respectively, showed good results for the VCAA device, with pressure over time being relatively low and relatively constant. Cylindrical energy absorption devices showed acceptable results for all three impact velocities.

FIG. **16**A shows predicted percent utilized displacement of VCAA and cylindrical energy absorption device (CA) designs at impact velocities of 5 meters per second (m/s), 6 m/s, 7 m/s, 8 m/s, and 9 m/s, as obtained from computational modeling. Results showed that VCAA designs yielded percent utilized displacements of greater than 90% at all impact velocities. Percent utilized displacement values calculated for cylindrical energy absorption devices were also excellent at all velocities, especially higher velocities.

FIG. **16**B shows in silico predictions of percent shock absorption efficiencies for VCAA and CA for impact velocities of 1 m/s, 2 m/s, 3 m/s, 4 m/s, and 5 m/s, wherein percent shock absorption efficiency was calculated by ideal exerted force divided by maximum observed exerted force in in silico models. VCAA energy absorption devices showed dramatic increases in shock absorption efficiency from these computational modeling experiments.

Helmet Comprising Energy Absorption Devices

This example shows a helmet system **200** comprising energy absorption devices disclosed herein for use in protecting a subject wearing the helmet. As shown in the diagrams of FIGS. **17**A-**17**D and the photographs of FIG. **18**A and FIG. **18**B, a plurality of energy absorption devices **100** comprising a first chamber **120** having a cylindrical side wall with a plurality of orifices **140** disposed in a side wall of the first chamber, a wall of a second chamber **111** coupled to an outer surface of a side wall of the first chamber, a high-strength fabric interstitial material **130** were coupled to an interior surface of a rigid helmet shell **190**. In this example, the rigid helmet shell **190** was configured as an American football helmet comprising a facemask **202** and a chinstrap **204**.

In many embodiments, the system comprises one or more pressure distribution plates **195**. The pressure distribution plates **195**, which are attached to a plurality of energy distribution devices **100** in the example shown in FIG. **18**E, aid in distributing the pressure exerted by the energy absorption devices **100** over a larger area of the object being protected from an external force (e.g. an external impact). In many cases, increasing the distribution of pressure over a larger area using a pressure distribution plate **195** decreases the risk of damage to the object being protected (e.g. the skin and/or skull of the subject wearing the helmet). A pressure distribution plate **195** can be coupled to one or more energy absorption devices **100**, for example, at a distal end of the one or more energy absorption devices **100**. In the example shown in FIG. **18**E, the system **200** comprises a plurality of pressure distribution plates **195**, with each pressure distribution plate coupled to the distal end of three energy absorption devices.

FIG. **18**C shows linear acceleration measured after contacting a helmet system **200** comprising a plurality of energy absorption devices containing a liquid water fluid (graph trace labeled "hydraulic"), as disclosed herein, or a helmet system comprising a plurality of air dampers (graph trace labeled "air") with an impactor at an impact velocity of 5.0 m/s. FIG. **18**D shows angular acceleration measured after contacting the helmet system **200** comprising a plurality of energy absorption devices each containing liquid water ("hydraulic"), as disclosed herein, or a helmet system comprising a plurality of air dampers ("air") with an impactor at an impact velocity of 5.0 m/s. FIG. **18**E shows linear acceleration measured after contacting a helmet system **200** comprising a plurality of energy absorption devices each containing a liquid water (graph trace labeled "hydraulic"), as disclosed herein, or a helmet system comprising a plurality of air dampers (graph trace labeled "air") with an impactor at an impact velocity of 7.4 m/s. FIG. **18**F shows angular acceleration measured after contacting the helmet system **200** comprising a plurality of energy absorption devices each containing liquid water ("hydraulic"), as disclosed herein, or a helmet system comprising a plurality of air dampers ("air") with an impactor at an impact velocity of 7.4 m/s. These results show that a system **200** comprising a plurality of energy absorption devices **100** coupled to a rigid solid support **190** can be used to protect an object (e.g. a subject's head) from shock impacts when the energy absorption devices employ water or air as the fluid. In particular, the energy absorption devices maintain low linear and angular accelerations following impact. Energy absorption devices containing liquid water show an advantage over air-filled energy absorption devices with respect to initial acceleration spike following impact.

While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

What is claimed is:

1. A device for absorbing external impact forces, comprising:

a collapsible elongated chamber having a first wall which resists circumferential expansion;

a refill chamber at least partially enclosing an outer surface of the first wall of the collapsible elongated chamber, wherein said refill chamber is configured to expand in response to an internal pressure;

a membrane disposed between the inner surface of the wall of the refill chamber and the outer surface of the first wall;

a reservoir space disposed between an inner surface of a wall of the refill chamber and the outer surface of the first wall, wherein an interior of the collapsible elongated chamber is in bidirectional fluidic communication with the reservoir space via at least one orifice disposed through the first wall; and

an incompressible fluid contained in the interior of the collapsible elongated chamber, wherein the reservoir space receives the incompressible fluid to expand the refill chamber as the incompressible fluid flows from the interior of the chamber through the at least one orifice when the chamber is compressed by the external impact forces, whereby the impact forces are absorbed or dissipated by the device.

2. The device of claim **1**, wherein the wall of the refill chamber is configured to circumferentially expand outward in a substantially radial direction in response to the internal pressure.

3. The device of claim **1**, wherein a wall of the refill chamber comprises an elastic material.

4. The device of claim **1**, wherein the reservoir space is in bidirectional fluid communication with an interior of a first collapsible elongated chamber and an interior of a second collapsible elongated chamber.

5. The device of claim **1**, wherein the incompressible fluid is water.

6. The device of claim **1**, wherein the collapsible elongated chamber is axially collapsible.

7. The device of claim **1**, wherein an orifice of the at least one orifice is disposed through the first wall at a proximal end of the collapsible elongated chamber, wherein an orifice of the at least one orifice is disposed through the first wall at a proximal end of the collapsible elongated chamber, or wherein an orifice of the at least one orifice is disposed through the first wall between the proximal end and the distal end of the collapsible elongated chamber.

8. The device of claim **1**, wherein an orifice of the at least one orifice has a cross-sectional area of from 1 mm^2 to 1,000 mm^2.

9. The device of claim **1**, wherein the cross-sectional area of the collapsible elongated chamber decreases linearly along a longitudinal axis of the device, from a proximal end to a distal end or wherein the cross-sectional area of the collapsible elongated chamber decreases non-linearly along a longitudinal axis of the device, from a proximal end to a distal end.

10. The device of claim **1**, wherein the membrane is a high-strength material, wherein the membrane comprises a permeable material or an impermeable material or wherein at least a portion of the membrane is mechanically isotropic.

11. The device of claim **1**, wherein the collapsible elongated chamber has an axial height of from 5 mm to 1,000 mm when undeformed.

12. The device of claim **11**, wherein the collapsible elongated chamber has an axial height of from 10 mm to 50 mm when undeformed or wherein the collapsible elongated chamber has an axial height of from 10 mm to 50 mm when undeformed.

13. The device of claim **1**, wherein the collapsible elongated chamber has a maximum width perpendicular to a longitudinal axis of from 5 mm to 50 mm when undeformed.

14. The device of claim **1**, wherein a maximum width of a proximal end of the collapsible elongated chamber is from 5 mm to 60 mm when undeformed or wherein a maximum width of a distal end of the collapsible elongated chamber is from 5 mm to 60 mm when undeformed.

15. The device of claim **1**, further comprising an elastically compressible material disposed within the first collapsible elongated chamber and coupled to an inner surface of the first wall at a proximal end of the device.

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